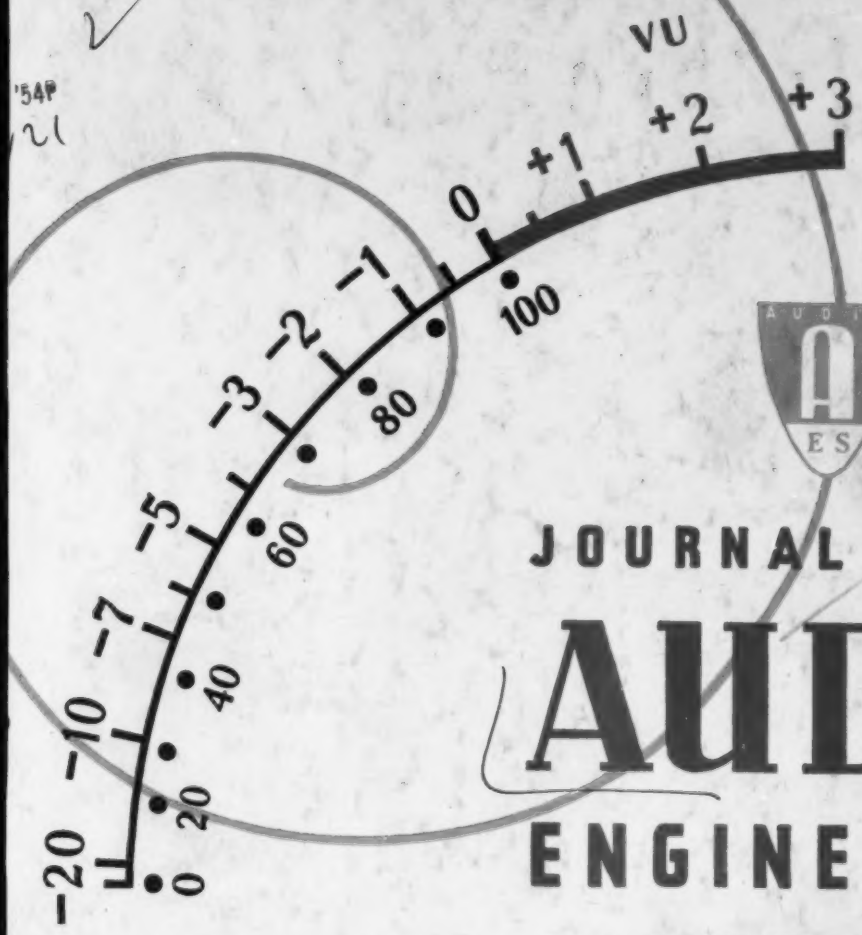

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Journal of the
AUDIO ENGINEERING SOCIETY

VOLUME 2 NUMBER 2

APRIL 1954

New Advances in Language Teaching---The Georgetown University Project*

MORRIS LEWIS GRODER†
Electrical and Physical Instrument Corporation, Long Island City, New York

In recent years, electronic devices have played an ever-widening role in the field of education. Georgetown University pioneered in the use of the tape recorder-reproducer, Educorder Dual, and other audio and visual devices for language teaching and multilingual interpretation. This paper describes the project at the University's Institute of Languages and Linguistics, the technical equipment used, teaching methods, and unique techniques devised to solve educational problems.

IN THE FALL of 1949, the School of Foreign Service of Georgetown University in Washington, D. C., opened its new department, the Institute of Languages and Linguistics. The widening scope of our international relationships had created an acute need for intensification of the practical training in linguistics and a growing quest for improvement in technical aids, in the teaching of languages.

The project was planned in three divisions: languages, linguistics, and methodology. The Division of Methodology, with which we are concerned at this time, was set up to conduct research and to experiment with existing and new techniques and equipment for the teaching of languages. This consisted in the main of sound recorder-reproducers, opaque, transparent, and motion picture projectors, and other audio-visual devices.

At present there are two major laboratories; the Audio-Visual and the Multilingual. A third major laboratory is under consideration. It will be devoted to visual methods of teaching and will utilize such devices as the Sonograph for phonetic work, and an audio-visual projector which combines sound with still pictures. With this instrument, a tape recording previously made by an instructor is played back. A photograph is projected on a screen, and the various objects in the picture are described in the language being studied. When the discussion of the photograph has been completed, a new photograph is automatically projected on the screen and discussed. This process is applied to a complete set of photographs. This has been proved to be an extremely useful device for vocabulary building.

For the present, the Audio-Visual Laboratory contains

* Presented at the Fifth Annual Convention of the Audio Engineering Society, New York, October 14-17, 1953.

† Chief Production Engineer; formerly Sound Engineer, Georgetown University, Washington, D.C.

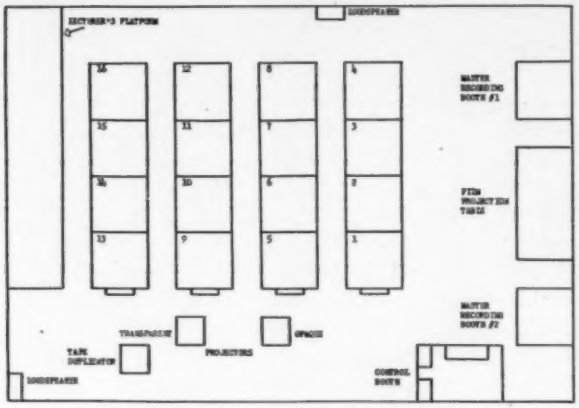


FIG. 1. Layout of Audio-Visual Laboratory.

both audio and visual devices. Figure 1 demonstrates the arrangement of the laboratory. This figure shows the lecturer's platform, loudspeakers, students' booths, control booth, master recording studios, motion picture projector, transparent projector, opaque projector, and tape-copying machine.

A standard procedure at the Institute is as follows: The instructor makes a master tape by speaking into a microphone in one of the master recording studios. The control booth contains two professional master recording machines, one for each studio. By means of a buzzer, the technician signals the instructor to start talking. The instructor then begins. If during his recording he makes a statement which he finds he would rather rephrase or delete, he operates a buzzer which records its tone on the tape. He then restates the phrase to his liking and continues to record. After the recording is completed, he plays the tape back at a fast speed and quickly locates the proposed deletion by means of the conspicuous buzzer tone. He cuts out the unwanted portion of the tape and joins the remaining ends together with splicing tape. By means of this technique, coughing, sneezing, book dropping, and other audible distractions can be deleted from the master tape.

While recording in the studio, the instructor keeps track of the amount of recording time remaining on the master reel by means of an IBM timer. This consists of a set of lights mounted before him in the studio. In a half-hour recording these lights flicker off one by one, every 2 minutes, as recording time is consumed. Also available in the studio is a stop-go switch which enables the instructor to start or stop the tape at will so that he can conveniently halt the recording and resume it at will. In this way he can stop during a recording if he desires to obtain a book for reference, answer a phone call, or smoke. The timer which informs the instructor of the recording time remaining is tied in with the stop-go switch so that its action is halted when the switch is thrown. In this way the timer always gives an accurate reading, no matter how long or how many times the recording is halted.

After the recording is completed and edited to the instructor's satisfaction, the desired number of tapes are made by duplicating the master recording on a high-speed copying machine (Fig. 2). This machine will produce up to nine tapes simultaneously. A half-hour long recording can be copied in about 9 minutes.

When the laboratory was first set up, the recording technician used one of the machines in a student's booth to record the master tape. Duplicate copies were made by using machines in other student booths. This, of course, tied up students' booths, consumed valuable technician time, and produced inferior copies owing to the differences in the machines.

One of the major advantages that sound recording offers is its ability to relieve the instructor of tedious repetitive and drill work, thus enabling more classroom time to be devoted to corrective work and creative effort. In general, students at the Institute are required to spend an hour and a half in laboratory work for each hour of classroom work.

As mentioned previously, one of the effective uses of the tape recorder-reproducer lies in the region of repetitive and drill exercises. For this application, the copy of the instructor's master tape, obtained from the school bookstore, may

FIG. 2. A nine-channel tape duplicator (courtesy Rawdon Smith Associates, Washington, D. C.).

FIG. 3. Student's booth (courtesy Georgetown University).

contain words which are repeated several times followed by a pause. This procedure may be followed throughout the recording. In order to avoid possible error by the student in his pronunciation, a space is left at the end of the tape for the student to record on. If no space remains, the student can record on a separate tape. The instructor, upon receiving the student's recording, will play it back at his convenience and make any necessary correction. This may consist in taking notes and discussing the recording with the student individually or in class, using the student's tape if necessary. The instructor may also record the correction and present this to the student for study.

At this time it may be advisable to examine the physical arrangement of one of the student booths. Figure 3 shows a student seated at one of these booths, recording. The front of the booth contains a hinged top which may be let down when the instructor is addressing the class. When the top is in the up position, the student is effectively seated in a private semisoundproof enclosure. In this situation, the student does not feel embarrassed by having others hear if she is struggling through a difficult pronunciation. The magnetic tape machine before her can be used for reproduction as well as recording her endeavors.

Upon first entering the laboratory as a new student, she has received oral as well as mimeographed instructions for operating the machine. Not only are the instructions presented in minute detail, but the student may also call upon the technician if she requires further aid.

The tape machine has the following controls: normal forward for listening, fast forward for reaching some particular passage quickly, and fast reverse which conveniently permits the student to play some particular material again and again if she so desires. Other controls include that of tone, volume, erase, record, and reproduce.

Figure 4 shows a portion of the Audio-Visual Laboratory in use as a special classroom. The instructor has just completed a special lecture, and the booth fronts are consequently down. The class is doing some work requiring the tape machines. By means of a selector switch and earphones installed at the end of each row, the instructor can listen to each student at work. In this case, the instructor, having heard a particular student who requires advice, has gone to the student's booth to discuss the matter with her. The instructor is standing at the left.

All booths can be electrically interconnected in various combinations to produce a variety of effects. A visitor monitoring the students' work by means of the selector switches and earphones located at the end of each row may find one student listening to Arabic, another student recording in Hindustani, and other students in various parts of the room listening to a conversation tape emanating from a Chinese master tape playing back in an empty booth. Such a tape contains a one-sided conversation with appropriate pauses. The student is required to fill in the second part of the conversation either *ad lib* or perhaps by translating from an English text. As the master recording is played, its sound is recorded on the student's tape. During the pauses, the student records his part of the conversation on his tape. The student then presents his tape to the instructor with both their voices recorded on it.

The engineer requires a definite amount of ingenuity to fulfill the requests of instructors in their search for more effective techniques. For example, one instructor requested a method whereby he might inject corrections on the tape, immediately following an error. One possible solution to this problem lies in the use of two tape machines (Fig. 5). The student's tape is played on machine 1. The sound

FIG. 4. Laboratory class (courtesy Georgetown University).

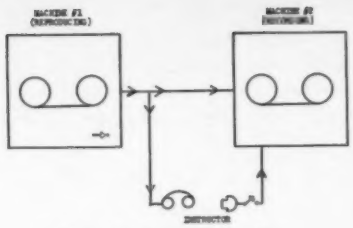


FIG. 5. Injection recording.

output of machine 1 is fed to the instructor's earphones and to the recording input of machine 2. Machine 2 contains a blank recording tape upon which the student's recording is being copied. When the instructor wishes to inject a comment, he stops machine 1 but leaves machine 2 running in recording position. The instructor turns on his microphone and records his comment on the tape in machine 2. When the comment has been completed, the microphone is turned off and machine 1 restarted. Machine 1 then continues to transcribe its material from the point where it had left off, and the process is continued under the instructor's control. The instructor presents the tape from machine 2 to the student for study and correction. When the student has no further use for the recorded material on his tape, he exchanges it at the school bookstore for a tape associated with his next lesson. The returned tape is sent to the technician who records new material on it.

Students are issued three tapes at the beginning of the school term. Two contain recorded material, and the third is used by the student for practice recordings. The recorded tapes may contain the following material: phonetic, vocabulary, grammar, conversation, literary, dramatic, musical, and linguistic. The average number of recorded tapes used by the student is sixty per language per semester. There are about 3500 master tapes now available for use at the Institute, covering thirty-six languages. The application of new devices includes the use of the Educorder Dual, a device for which the Director of the Institute, Professor L. E. Dostert, is responsible. This is a machine which uses standard quarter-inch width recording tape in a system commonly known as the dual track. Instead of recording across the complete quarter-inch width of tape, two parallel magnetic tracks are used, each about an eighth of an inch in width. Upon one of the tracks, the instructor has recorded a lesson in phonetics. The student listens to this recording while simultaneously imitating the instructor's voice on the second track. After this, he listens to both recordings simultaneously and judges just how closely his pronunciation parallels that of the instructor. This machine can also be used for two-part conversations, one of which is provided by the instructor and the other by the student.

Facilities are also available for listening to standard disk recordings such as folk songs. Means are also provided for recording foreign broadcasts to be used for translation, dialect, and similar purposes.

The Institute has three other student laboratories. These laboratories contain recorder-reproducers installed in semi-soundproof booths and function as study rooms. Each laboratory is provided with two tape splicers to facilitate the repair of tapes which might be torn by the students. Tape recorder reproducers in both portable and table models are also available for use in the regular classrooms. Sixty-eight machines serve the 400 language students studying at the Institute.

The current estimate is that the preventive maintenance program requires a total of 20 man-hours of service per machine per year. Some of the machines have been in use for 4 years. Components which have been replaced in them include magnetic heads, belts, capstans, and electronic tubes. The technical personnel consists of a sound engineer aided by part-time technicians whom he has trained. These technicians are members of the student body who are supplementing their finances by working for the school—a common practice in educational institutions.

As a result of conclusions drawn from the Institute's findings, a large language laboratory was set up for the regular foreign-language students of Georgetown University College of Arts and Sciences and the School of Foreign Service. Figure 6 shows a view of this laboratory. It consists of 120 semisoundproof booths equipped with earphones and with selector switches which the student adjusts so that he can receive his particular language drill lesson. The booth fronts can be raised for listening to the lesson privately, or lowered for viewing a visual aid screen at the front of the laboratory. A bank of twelve playback ma-

FIG. 6. Poulton Hall Language Laboratory (courtesy Chase News Photo, Washington, D. C.).

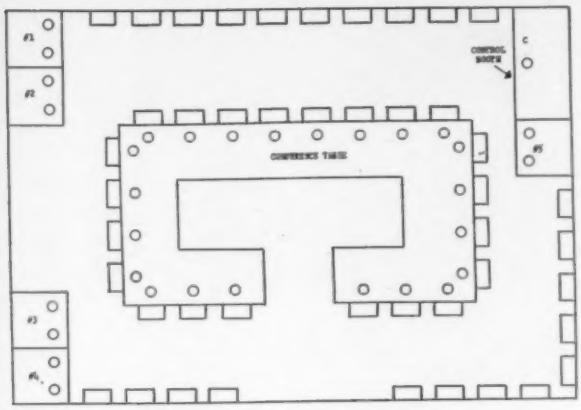


FIG. 7. Layout of Multilingual Conference Room.

chines feed recorded material to the booths through the selector switches. Class schedules are arranged to accommodate various languages and language levels. The recorded material is essentially language drill. Since there are no tape machines installed in these booths, ten special recording booths are located about the room for the use of the students. Five loudspeakers about the room are available for public address purposes.

Returning again to the Institute of Languages and Linguistics, Fig. 7 shows the arrangement of the Multilingual Conference Room which is a simultaneous and consecutive language translation laboratory. This is essentially the same sort of IBM equipment used at United Nations Headquarters for simultaneous translation of languages. Five translating booths and one control booth are arranged about this room. Each translation booth contains two pairs of earphones and two microphones. One of these translating positions in each booth is for use by a relief translator during long programs. The control booth operator maintains the proper listening levels in the speakers' circuits and switches in the microphones about the table, one by one as required. Otherwise, in the heat of discussion a veritable babel might ensue if all microphones were left in the on position. Each selector switchbox in both the Multilingual Room and in the 120-booth language laboratory previously described contains a volume control for the listener's convenience.

One method of using the facilities of this room consists in having a speaker discuss some subject at the table. The students in the booths listen and translate simultaneously into other languages. Other students in the room adjust their selector switches to listen to the desired translator. If the speaker is discussing something in Korean and one of the translators in the booths does not understand Korean but does understand Spanish, he can adjust his selector switch to receive the Spanish interpretation and translate from Spanish into his required language. In other words, the student will be listening to a translation of a translation. A discussion is possible among six people, each speaking a different language. For example, student A makes a statement in German, speaking into his microphone. This is translated simultaneously into the other five languages by the translators. Student B replies in Italian, and this is simultaneously translated into the remaining five languages. This enables student A to receive, in German, student B's reply, which was originally spoken in Italian.

The Multilingual Room is also coupled to the Audio-Visual Laboratory by means of interconnecting cables. This permits recordings to be made of visiting speakers and language students. In this manner important discussions are made available for study by language students, and translation students may listen to recordings of their own voices for critical evaluation. Cables are also available for remote control of the recording machines in the Audio-Visual Laboratory so that the multilingual control booth operator can make continuous recordings of discussions without leaving the control booth. Signaling and intercommunication lines between the control booths of both laboratories are also available for use.

Several photographs of interest are shown in Figs. 8 through 11. Figure 8 shows a view of the booth as seen by the student. The front panel is in the closed position. The earphones can be seen at the upper left, the push-to-talk microphone at the lower left, the mechanically operating portion of the recorder-reproducer is shown in the background, and in the foreground at the left may be seen the following controls: record-playback, tone, volume, and power.

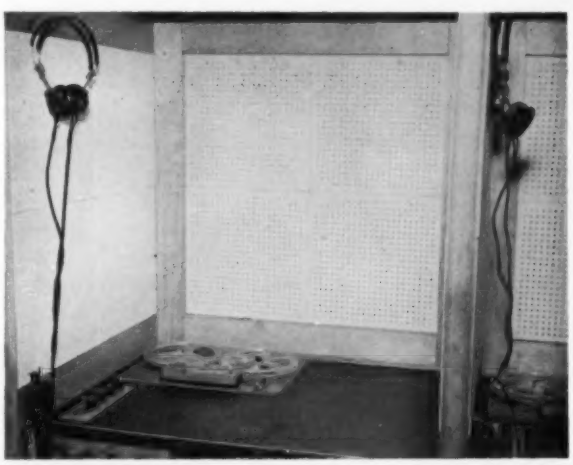


FIG. 8. Student's recorder-reproducer (courtesy Educational Laboratories, Inc., Washington, D. C.).

Figure 9 is a photograph of a six-channel copying machine, commercially manufactured, used in installations smaller than that of the Institute. Figure 10 exhibits a master control booth demonstrating microphones, control panel, and timer equipment. Figure 11 shows a typical thirty-booth commercial installation. Provision is also made here for audio visual study.

To summarize, technical aids in language teaching enable the instructor to devote more time to creative effort and corrective work by using these aids for rote detail learning. These aids also afford the opportunity for more effective teaching methods, new techniques, and improved language mastery.

I should like to thank the Reverend Edmund A. Walsh, Regent of the School of Foreign Service of Georgetown University; Professor L. E. Dostert, Director of the Institute of Languages and Linguistics; K. F. Kellerman of Educational Laboratories Inc., M.C. and F. Rawdon Smith of Rawdon Smith Associates; A. B. Holt of International Business Machines; and Chase News Photo of Washington, D. C., for the information facilities made available by them.

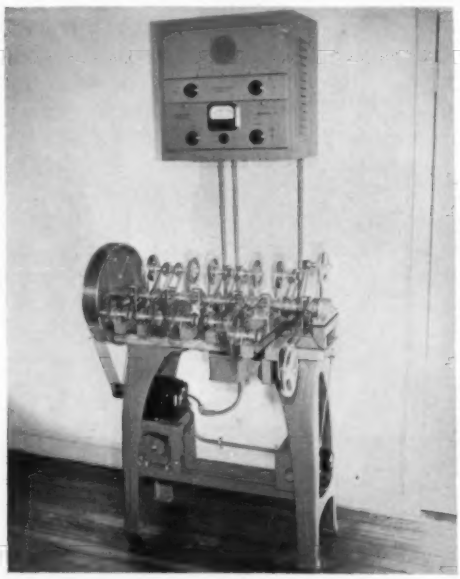


FIG. 9. A six-channel tape duplicator (courtesy Rawdon Smith Associates, Washington, D. C.).

FIG. 10. Instructor's recording studio (courtesy Educational Laboratories, Inc., Washington, D. C.).

FIG. 11. A thirty-booth audio-visual laboratory (courtesy Educational Laboratories, Inc., Washington, D. C.).

An Analytical Approach to Phonograph Pickup Design*

WALTER O. STANTON†
Pickering and Company, Inc., Oceanside, New York

ONE OF the most striking characteristics of current audio engineering practice is the emphasis on control of distortion down to levels that were considered utopian a few years ago. Another important condition, generally agreed to exist, is that at this point in audio history amplifiers perform far better than the transducers in common use. The pickup and loudspeaker are the "choke points" on quality in even the best reproducing systems available. Thus the engineer knows that he can get the greatest leverage on improving over-all system performance by the design of a better transducer or the improvement of one he already has.

To illustrate some of the most recent techniques in distortion control, this paper discusses the design factors that affect the frequency bandwidth of moving-iron magnetic pickups. Frequency distortion is, of course, only one of several forms of distortion that the audio designer must keep at very low levels in every component of a system. Waveform distortion and phase distortion should probably be put beside frequency distortion to make up the three most important types, from the audio engineer's point of view. This discussion is limited to frequency distortion in pickups, so that a useful amount of time can be given to this subject, and techniques outlined that are adequate to the actual design of a wide-range pickup-arm system.

Figure 1 charts the trend over the past eight years in over-all system bandwidth, taking into account the changes and improvements in records, recording techniques, electronic equipment, and transducers. The chart should naturally be regarded as a generalization, intended to show the average movement of frequency-response practice among a great number of audio equipments of widely varying characteristics.

As shown, the pass band of this *average* audio system in 1945 and earlier was from 100 to 5000 cps. Beginning in 1946 and 1947, there was a fairly sizable shift to equipment with a pass band wider by an octave at each end, an extension downward from 100 to 50 cps and upward from 5000 to 10,000 cps. Today, the mark we have set ourselves to aim at is again wider by about an octave at each end, running from about 25 cps to about 20,000 cps. It must be admitted that a minority of components, and those mainly amplifiers, have yet reached this truly "wide-range" character.

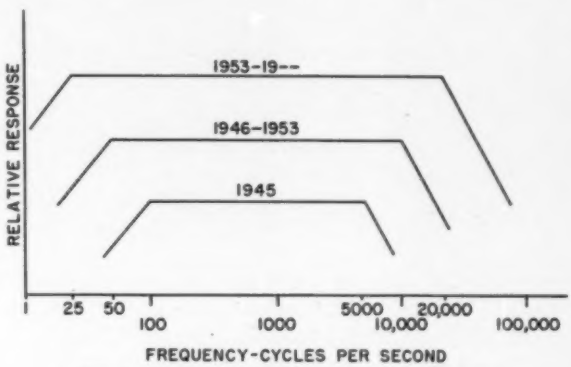


FIG. 1. Chronological trend in system response.

The design techniques described in this paper, using relatively simple mathematical tools, can be used to widen the pass band of the pickup-arm system so that it fully realizes this frequency response now conceived to be ideal. Enough experience has been gained to make such a widening practical and desirable. This pass band extension has actually been carried out in an available pickup-arm system with a shifting of the lower response limit down to 25 cps and the upper limit to 20,000 cps.

Figure 2 charts this new response curve, showing a bandwidth which will satisfy the needs of the most refined systems conceivable today. We note that the pass band is terminated at both ends by sharp rolloffs. At the low end, the rolloff is caused by the mechanical resonance between the tone arm mass and the compliance, or, inversely, the stiffness of the generating system. At the high end, in moving-iron magnetic cartridges, the rolloff is caused by electrical res-

* Presented at the Fifth Annual Convention of the Audio Engineering Society, New York, October 14-17, 1953.
† President.

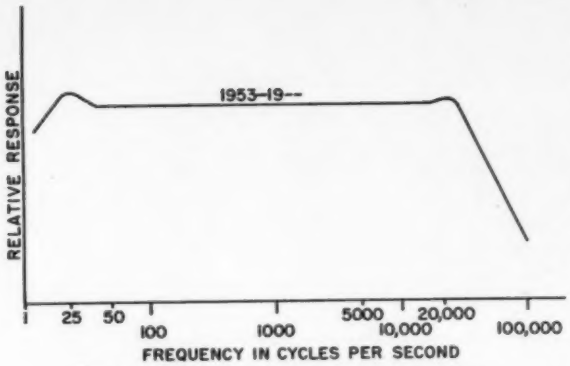
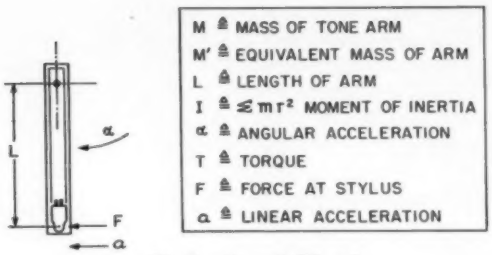


FIG. 2. Frequency response of a modern pickup.



(1) $T = I\alpha$ and $FL = I\alpha$

Since $I = \frac{ML^2}{3}$ and $\alpha = \frac{a}{L}$,

(2) $F = \frac{M}{3}a$

and if $\frac{M}{3} \triangleq M'$,

(3) $F = M'a$

FIG. 3

onance between the cartridge inductance and capacitance. Thus the low-frequency limit of the pass band can be controlled by choice of mechanical characteristics of the cartridge and arm, and the high-frequency limit can be controlled by electrical characteristics of the coil. It should be emphasized again that this applies to moving-iron magnetic pickups.

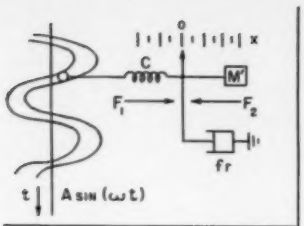
Control of the inductance and distributed capacitance of the coil to set a high-frequency limit must be balanced against another important design objective which depends on coil constants—the development of as much voltage by the pickup as possible. This latter objective, of course, requires that as many turns as possible be placed on the coil. Design choices here are particularly critical because the voltage varies only directly with the number of turns, whereas the inductance goes up in proportion to the *square* of the increase in the number of turns. If we double the number of turns we get approximately a 6-db increase in voltage, but an increase of about four times in inductance. Equations covering the relationships between the high-frequency limit and these factors are developed later in this paper.

Considering the low-frequency end of the response curve first, we look at the mechanical factors which were identified above as controlling elements. Figure 3 represents pictorially and mathematically a simple tone arm pivoted about one end with a phonograph cartridge at the other. In theory as well as in practice, this is the elementary pickup-arm combination. To describe the mechanical system in terms of inertia and angular acceleration, we write expression 1. Following algebraic rules we develop expression 2, describing the force in terms of mass and linear acceleration. Since the movement of the cartridge stylus caused by the groove modulation on the record is small compared to the length of the tone arm, it is allowable to convert the angular momentum problem into one of linear momentum. It will be noted that for the inertia term I, the standard definition of a straight bar moving about an axis of rotation has been applied. This formula may be found in any textbook on analytical mechanics, or it can be derived from fundamental definitions.

In equation 3 the force term applies to the force at the stylus of the cartridge. M' is the effective mass of the tone arm, and a is the linear acceleration. This entire operation has been performed in order to change the expression to one of translation rather than rotation. It is simpler to describe the system in linear terms because the record groove can be thought of as being modulated about either side of an axis along a linear time scale. The problem can be solved in angular terms just as easily, but perhaps the physical meaning of the analysis is not as obvious.

Figure 4 is a mechanical schematic which describes the record groove, cartridge, and tone arm system. The equivalent mass of the tone arm, M', as developed in Fig. 3, is coupled to the record groove through the compliance, C, of the cartridge. Arm damping is represented by the term f_r and is shown on the schematic as a dashpot. Below resonance we know that the tone arm will follow approximately the modulation in the record groove. Above resonance, because of the compliance of the cartridge, the tone arm remains stationary relative to the groove modulation. At resonance, of course, we expect the greatest motion to take place. In order that the cartridge shall generate a distortion-free signal, the tone arm must remain stationary relative to groove modulation and yet respond to extremely low-frequency signals such as are developed by record eccentricity and so forth. In other words, for minimum distortion there should be relative motion between the tone arm and stylus down to the lower end of the audio pass band, and no relative motion at the subaudio frequencies below the pass band.

It is convenient, therefore, to express the lateral motion



A sin (ωt) ≙ MECHANICAL SIGNAL
F1 & F2 ≙ MECHANICAL FORCES
C ≙ PICKUP COMPLIANCE
M' ≙ EQUIV. ARM MASS
x ≙ ARM RESPONSE
fr ≙ DAMPING - ARM

$$[A \sin(\omega t) - x]\frac{1}{C} = M'\ddot{x} + f_r\dot{x}$$

$$\left(M'p^2 + f_r p + \frac{1}{C}\right)x = \frac{A}{C}\sin \omega t$$

If $p = j\omega$, then

$$x = A\,\frac{1/C}{(1/C - \omega^2 M') + j\omega f_r}$$

When $f_r \to 0$, and $1/C - M'\omega^2 \to 0$

$$\omega \to \sqrt{1/M'C}$$

FIG. 4

of the arm, in response to groove modulation, as a function of frequency. To set up equations for this purpose, we show along the scale marked x the displacement of the tone arm from its average position, this average position corresponding to the zero axis of the groove modulation. The midpoint on the scale marked zero corresponds to this zero axis or average position, and displacements of the tone arm to follow the modulation are measured by positive and negative values of x, depending on the direction of modulation.

If we now consider the forces acting at the point of junction between the compliance, C, and the mass, M, we recognize that force F_1 developed by the spring is equal and opposite to the force F_2 developed by the reaction of the tone arm mass and viscous friction, f_r. Thus we can write $F_1 = F_2$. If the amplitude traced by the stylus is subtracted from the displacement of the junction point along the x axis, the difference is the amount of compression in the spring, which when multiplied by the stiffness factor gives us a force term. The force F_2 is developed by the mass acceleration plus the friction due to the lateral velocity of the tone arm. Rewriting this expression and using the Laplace transformation, we arrive at an expression for x. This equation describes the amplitude *vs* frequency characteristic of a typical arm-cartridge system, x being the amplitude of lateral motion of the arm. Near resonance we see that the term $(1/C)-M'\omega^2$ approaches zero, and ω approaches $(\sqrt{1/M'C})$. This demonstrates that, because of the exponential relationship which exists between resonant frequency and the mass and compliance terms, large changes in mass and/or compliance are necessary to effect relatively small changes in resonant frequency.

This exponential relationship throws needed light on the suggestion, made so often recently, that the compliance of pickup cartridges should be increased. The reasons for increasing the compliance of a pickup are well known, and every designer worth his salt is fully conscious of them. He has a number of conflicting requirements to satisfy, however. It is obvious from the equation just developed that a very large change in compliance is required to effect an appreciable change in the lower limit of the pass band. To get from 50 cps down to 25 cps, for instance, a change of 2:1, the compliance must be increased by a factor of 4. An increase in compliance of this magnitude may well create some difficult mechanical problems. The stiffness of the cartridge is an essential mechanical element which centers the moving part of the cartridge and at the same time drives the tone arm across the record against any friction which may be present. Stiffness cannot be reduced below the level necessary to make the system as a whole perform as intended.

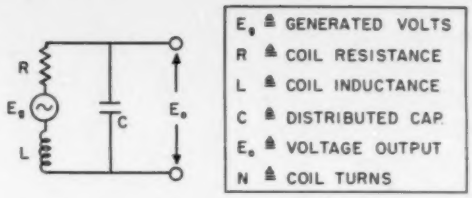
The problem is further complicated by the fact that a cartridge manufacturer must create a product that can be rather universally applied. It must be capable of use with a wide variety of tone arms. Many of the tone arms on record changers are extremely light. In other words, the term M has a small value. Some manual arms are very massive with large M values. Representative M values vary not by a factor of 2 or 3, but from 8 to 20 times. When used with an extremely massive arm a particular cartridge may exhibit a low resonant frequency and wide pass band. In a light arm, obviously the lower limit of the pass band will be raised. Thus the achievement of a proper pass band, as well as proper mechanical functioning of the pickup-arm system, requires the exercise of keen practical judgment in the assignment of a compliance value to the cartridge, and present conditions set limits on that value.

It should be unnecessary, in view of the foregoing, to comment on the suggestion now seriously made in some quarters that the compliance of a stylus should be infinite, that is, that no restoring force should be used in the generating system. Some stiffness is absolutely essential in a pickup-arm system of the type now universally used, to move the arm across the record and to keep the moving parts of the cartridge centered. There is a further and equally damaging effect of excessive compliance. As shown in this paper, the lower limit of the frequency pass band is a function of the compliance, among other factors. A lower resonant point, which was low enough to let subaudio

noise signals into the system, would open a source of serious distortion. Such subaudio signals are often of very large amplitude, and, as is well known, can cause excessive distortion by overloading some parts, or all, of the system. Thus from several points of view it is extremely desirable to establish the compliance of the cartridge at a level which carries cartridge response only to the lower end of the audio band, with arm response in the subaudio noise spectrum.

High-frequency response, as pointed out above, can be limited in the moving iron pickup by electrical resonance in the winding, if sufficient turns are placed on the pickup coil. There are many good reasons for making every effort to raise the output of a pickup, and adding turns is the easiest way to do this. Today, the mechanical tracking problem is no longer the limiting factor if 20-kc response is considered adequate. Therefore, it is reasonable to study separately the electrical system within the pickup as it affects the upper limit of the pass band.

Figure 5 represents a typical pickup generating system. Equation 1 describes the output voltage E_o as equal to the product of the generated voltage, E_g, and the transfer function of the source impedance. Equation 2 is the familiar expression for the undamped natural frequency and is approximately equal to the resonant frequency for small values of R. Since L, the inductance, is proportional to the number of turns squared and the distributed capacitance is directly proportional to the number of turns, we can write equation 3, which shows that the resonant frequency is radically affected by changes in the number of turns. Doubling the



$$(1)\quad E_o = E_g \frac{1/C}{(1/C - \omega^2 L) + j\omega R}$$

$$(2)\quad \omega_N = \sqrt{1/LC}$$

Since $L \propto N^2, C \propto N$,

$$(3)\quad \omega_N \propto \frac{1}{N^{3/2}}$$

$$(4)\quad E_g \propto N$$

FIG. 5

number of turns, for example, may lower the top limit of the pass band to a third of its former value. The turns factor is thus controlled, in relation to other characteristics of the cartridge, to put the upper resonance at the wanted point on the frequency curve.

In all the foregoing, numerical design constants such as might apply to a particular pickup have been avoided, in order to keep the discussion perfectly general. However, the analysis presented here, though admittedly limited, can be directly applied to typical pickup-arm design problems. If properly weighted with experience, the methods described will furnish guidance toward the production of a system of improved frequency characteristics.

Amplifiers and Superlatives*

An Examination of American Claims for Improving Linearity and Efficiency

D. T. N. WILLIAMSON, *Ferranti Research Laboratories, London, England*
P. J. WALKER, *The Acoustical Manufacturing Company, Huntington, England*

Recent articles, particularly in the United States, have shown that some confusion of thought exists about the "goodness" of an amplifier for reproducing sound. This has been accompanied by a debasement of the terms used to describe the properties of an amplifier; words that have a precise meaning when standing alone become meaningless when qualified by superlatives. This article, which starts with a discussion of what constitutes a good amplifier, attempts to clear up some misconceptions and generally to clarify the position.

THE MOST commonly specified parameter of an amplifier is its harmonic distortion or intermodulation content, and this has tended to be regarded as the primary standard of "goodness." In 1944, one of the writers suggested[1] that a standard of 0.1% total harmonic distortion at maximum output was a good level of performance to aim at. Such a low distortion content is readily achievable by modern design methods and is, in fact, undetectable by listening tests, however refined. This arbitrary figure was chosen, not because it was the maximum permissible, but because, being rather lower than was absolutely necessary, a good margin is left for any deterioration of the equipment when in service.

The requirements for a good amplifier were listed in the article already mentioned but are worth repeating and extending. These are:

1. Negligible nonlinearity distortion up to the maximum rated output. (The term "nonlinearity distortion" includes the production of undesired harmonic frequencies and the intermodulation of component frequencies of the sound wave.) This requires that the dynamic output-input characteristic be linear within close limits up to the maximum excursion of any waveform, with frequency components inside and outside the working range, which is likely to be fed to the amplifier. This should hold good under conditions of varying load impedance such as are likely to be encountered in practice.

2. Linear frequency response within the audible frequency spectrum of 10 to 20,000 cps.

3. Negligible phase shift within the audible range. Although the phase relationship between the component frequencies of a complex steady-state sound does not appear to affect the audible quality of the sound, the same is not true of sounds of a transient nature.

4. Good transient response. In addition to low phase and frequency distortion, other factors which are essential for the accurate reproduction of transient waveforms are the elimination of changes in effective gain due to current and voltage cutoff in any stages, the utmost care in the design of iron-cored components, and the reduction of the number of such components to a minimum. Changes in effective gain during "low-frequency" transients occur in amplifiers with output stages of the self-biased class AB type, causing serious distortion which is not revealed by steady-state measurements. The transient causes the current in the output stage to rise, and this is followed, at a rate determined by the time constant of the biasing network, by a rise in bias voltage which alters the effective gain of the amplifier.

5. Low output resistance. This requirement is concerned with the attainment of good frequency and transient response from the loudspeaker system by ensuring that it has adequate electrical damping. The cone movement of a moving-coil loudspeaker is restricted by air loading, suspension stiffness and resistance, and electromagnetic damping. The efficiency of a baffle-loaded speaker is rarely higher than 5 to 10%, and the air loading, which determines the radiation, is not high. Electromagnetic damping is therefore important in controlling the motion of the cone. This effect is proportional to the current which can be generated in the coil circuit and is therefore proportional to the total resistance of the circuit. The output resistance of the

* Reprinted through the courtesy of the authors and *Wireless World* (September, 1952).

[1] M.O. Valve Co., Ltd. Internal Report No. Q253, later published as "Design for a High-Quality Amplifier," D. T. N. Williamson, *Wireless World*, April-May, 1947.

amplifier therefore should, in general, be much lower than the coil impedance.

6. Adequate power reserve. The realistic reproduction of orchestral music in an average room requires peak power capabilities of the order of 15 to 20 watts when the electro-acoustic transducer is a baffle-loaded moving-coil loudspeaker system of normal efficiency. The use of horn-loaded or other efficient loudspeakers may reduce the power requirement to the region of 10 watts. In an amplifier for the best possible quality it is, of course, assumed that output peaks required in practice will be comfortably below the maximum available. Even so, good design should ensure that the overload characteristic will not suffer temporary paralysis or "blocking" on momentary overload.

7. The level of hum and noise should be at least 80 db below maximum output.

This is a formidable specification, and by no means every amplifier styled as "high quality" will meet it. However, provided that these requirements are met *in every respect* and that extraneous components occurring within the audio range (produced either by components inside or outside that range) do not exceed a small fraction of 1%, any amplifier will sound as good as any other amplifier and it becomes impossible to "improve" a power amplifier in the sense of producing better sound.

EFFICIENCY

On the other hand it is, of course, absurd to say that amplifiers cannot be improved in any sense. Efficiency, compactness, and reliability are important, and it is with regard to these factors that improvements are possible and in many cases desirable. The size and purpose of an amplifier will determine how much weight should be given to each of these factors.

In small amplifiers with power outputs below 20 watts, power efficiency is not usually of prime importance, and other considerations such as ease of construction and certainty of results may easily outweigh it. With large amplifiers, efficiency becomes a very important factor. Sometimes it is not possible to produce a high output *unless* the efficiency is high, because of valve dissipation limits.

CONTROLLED AND UNCONTROLLED PRODUCTION

The designer's aim is (or should be) to produce the best possible sound for those who will ultimately make use of his efforts. If he designs for construction not under his control, he must, as far as possible, ensure that every amplifier made will meet his performance figures without undue difficulty and with the employment of limited measuring equipment. In such a case, the avoidance of circuitry which is not straightforward, or in which deviations from specification in the values and construction of components is liable to produce poor results, is paramount.

The designer who has control over the production of the complete equipment has a different set of problems. He has much greater freedom of choice, and it is likely that he will arrive at different circuitry.

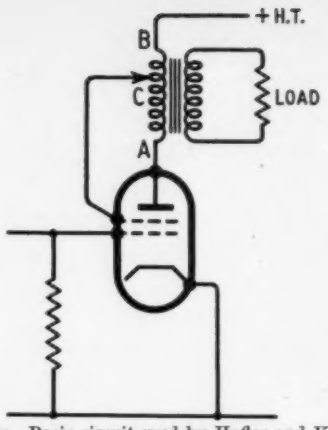


FIG. 1a. Basic circuit used by Hafler and Keroes.

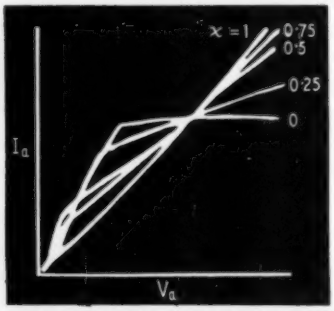


FIG. 1b. Oscillogram showing transition of I_a-V_a curves from tetrode to triode form as the tapping point in Fig. 1a is moved from *B* to *A*.

The amplifier which was described in *Wireless World*, April-May, 1947, is an example of the first kind of circuitry. The success it has achieved since then, in the hands of people with widely varying degrees of skill, is indicative that trouble-free performance is readily obtainable with only simple adjustments. This amplifier was based upon a triode output stage with a good output transformer, the performance of which was improved by over-all negative feedback.

The only valid criticism which can be made about its performance is on the score of efficiency. The output of about 15 watts is produced for an h.t. consumption of 56 watts, an efficiency of only 27%. By the use of tetrodes as output valves this could be raised to the order of 35 to 40%, which means that, for the same power consumption, the output could be increased to 22 watts, or, alternatively, that the power consumption could be reduced by about 20 watts.

Whether this is worth doing or not is problematical. In the designer's opinion, the additional risk of trouble in un-

skilled hands outweighs the advantage of higher maximum power output, as in the vast majority of cases even the present level of output cannot be fully utilized. The reduction in power consumption and h.t. voltage would not greatly affect the cost, although it would give a higher factor of safety for the capacitors in the circuit. There is, however, no evidence that this is at present inadequate.

CIRCUITS WITH DISTRIBUTED LOADS

Articles[2,3] have recently been published in the United States claiming the superiority of a so-called "ultralinear" output circuit in which the output valves are used as tetrodes, with negative feedback applied nonlinearly by connecting the screens to a tap on the primary of the output transformer. It is stated that the performance is audibly improved over that of triodes with similar degrees of negative feedback.

The present writers do not believe this claim. The circuitry which forms the basis of these American claims for "ultralinearity" and higher efficiency has, in fact, been familiar in this country for several years, and the technique has been further developed and used in a commercially produced high-quality amplifier.[4,5] It consists of the distribution of the load impedance between the electrodes of each output valve in order to obtain the optimum performance from that valve.

In its simplest form, and as used by Hafler and Keroes, the circuit arrangement is as shown in Fig. 1. The circuit is normal, except that the screen of the tetrode can be tapped on the output transformer primary winding, thus coupling it to the anode in any ratio, and rendering a section of the load impedance common to both electrodes. If the tap is affixed at point *A*, giving a coupling factor of unity, the stage behaves as a triode, its performance being determined by the dynamic characteristic of the screen and control grid, and if the tap is shifted to point *B*, the coupling factor is zero, and the stage behaves as a simple tetrode. If now the screen is tapped at intervals between point *B* and point *A*, there will be a progressive inclusion of the load impedance in the screen circuit and a progressive change from tetrode characteristics at *B* to triode characteristics at *A*.

It is convenient to consider the stage as being a tetrode with negative feedback applied to the screen. It differs from a tetrode stage with feedback applied to the control grid, first in that the screen introduces a nonlinear element in the feedback loop, and second because, as the degree of feedback

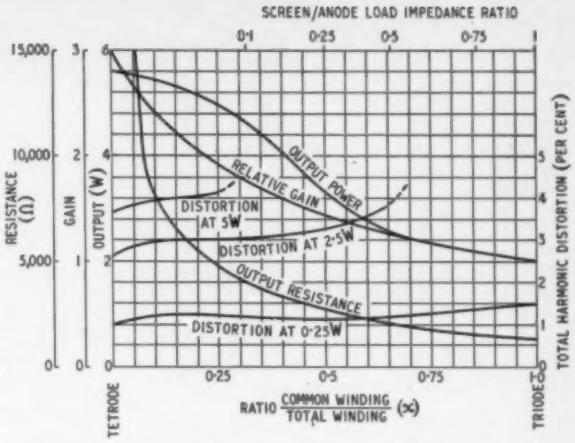


FIG. 2. Curves of output power, relative gain, output resistance, and distortion for the circuit of Fig. 1. The distortion components are predominantly second and even harmonics.

is increased, the permissible anode swing is decreased, owing to anode current cutoff on the negative excursions of screen voltage, until finally the I_a-V_a curves become those of a triode. A more complete account of the behavior of the circuit is given in the Appendix.

The curves of Fig. 2, which apply to a single valve, show the effect of changing the tapping point. The output at the point of overload, the relative gain, and the output resistance decrease as the degree of feedback is increased, the output resistance decreasing very rapidly because it is dependent, not on the gain reduction, but on the amplification factor, which undergoes a large change.

The distortion at constant output, which is predominantly second harmonic, rises slowly at first until the point of overload is reached. Since the maximum power output is progressively reducing, the distortion curves for maximum output or a percentage of maximum output will show a progressive reduction from tetrode to triode operation.

In view of the increase in distortion, as shown in Fig. 2, it would appear that there is little to be gained by the use of this circuitry, since a simple tetrode, with feedback to the control grid, would give a similar reduction of output resistance, and this would be accompanied by a progressive reduction in distortion. This is indeed true in the case of a single valve.

When push-pull connection is considered we obtain a different state of affairs, because of the cancellation of second harmonic components, and we arrive at the curves shown in Fig. 3. The general shape of the curves is maintained under varying loads. With up to 30% of the winding common to screen and anode the reduction in distortion is greater than the reduction in gain. This "something for nothing" is small, however, and can be lost or even reversed

[2] Hafler and Kehroes, "An Ultralinear Amplifier," *Audio Eng.*, pp. 15-17 (November, 1951).

[3] Hafler and Keroes, "Ultralinear Operation of the Williamson Amplifier," *Audio Eng.*, pp. 26-27 (June, 1952).

[4] First introduced in 1945; see advertisement of the Acoustical Manufacturing Company in *Wireless World*, p. 10 (July, 1945).

[5] Moir, "Review of British Amplifiers," *FM-TV*, pp. 30-32 (October, 1951).

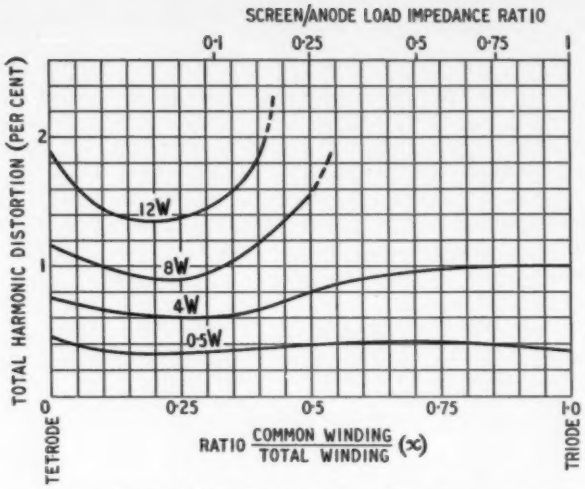


FIG. 3. Curves of distortion for a push-pull arrangement (predominantly third and odd harmonics).

if there are appreciable departures from precise balance at any frequency.

It is, of course, not essential to have the screen tapped directly on the primary winding, and an auxiliary winding tightly coupled to the primary (ideally in the form of a bifilar winding) may be used. This has the advantage that the screen supply voltage may differ from that of the anode to give optimum operating conditions.

THE "ACOUSTICAL" CIRCUIT

A further development of this circuit ("super-ultralinear," perhaps?) used in the Acoustical "Q.U.A.D." amplifier and its predecessor takes the common portion of the winding and inserts it in the cathode, giving the circuit of Fig. 4. As far as the anode and screen circuits are concerned, this arrangement is identical to that of Fig. 1 (neglecting winding resistance and leakage reactance). The only difference lies in the grid circuit, since that portion of the voltage appearing across the common winding is now applied in the grid circuit as over-all negative feedback. It is, of course, feedback of the most desirable kind, since it is the most practical method of applying voltage feedback over a single stage without either throwing gain away wastefully or increasing the load on the previous valve.

Since the screen is now connected to a decoupled point, it follows that the designer is free to use different voltages for screen and anode if required, without the necessity of additional windings, with their attendant disadvantages. Further, the arrangement makes it possible to provide the optimum degree of smoothing for the anode and screen supplies. The grid resistor may be taken to the cathode end of the common winding if desired, with the result that the input resistance is increased, thus facilitating the design of the previous stage and reducing the value of the coupling capacitance necessary.

The use of all the electrodes in this way gives additional flexibility in design, so that the parameters of the output stage may be varied to suit the penultimate stage—a technique giving greater scope in arising at a well-balanced ratio of stage distortions and hence an optimum final design. In the output stage of the Acoustical "Q.U.A.D." amplifier, using two KT66 valves, the values are so chosen that an output of 12 watts is obtained from a 320-volt supply with a grid-to-grid input of 72 volts peak, the input resistance being 1 megohm. The total harmonic distortion of the output stage alone is not more than 0.7%, and the output resistance is approximately half the load resistance.

By comparison with the same valves used as triodes to obtain the same output, the following advantages are apparent:

1. Distortion is less than half that of triode connection, owing to the cathode and screen feedback.

2. Efficiency is increased from 27 to 36%, resulting in the h.t. voltage being lower by about 100 volts, thus simplifying reliability problems both in the amplifier itself and throughout the range of preamplifiers, tuners, etc., which may take their supply from it.

3. Less smoothing is necessary for equivalent hum levels.

Additional over-all negative feedback can be applied to the complete amplifier, and with the ratios used in the above example, 8 db less feedback is required for a given level of distortion than with triodes. This assists in maintaining a good margin of stability and reduces the effect of overloading due to the presence of frequencies in the input which are outside the effective feedback range.

There remains the question of output resistance to be considered, about which there appears to be some confusion. This is probably due to the general use, as a measure

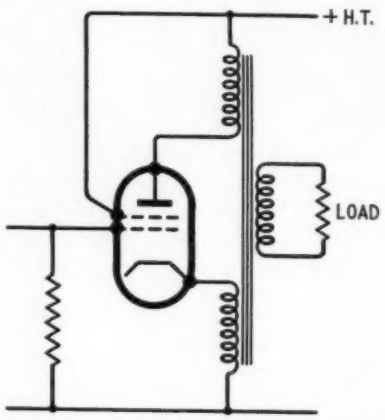


FIG. 4. Basic circuit used in the Acoustical Manufacturing Company's "Q.U.A.D." amplifier and its predecessor.

TABLE I

Parameter	Triode-connected tetrodes (class A)	Tetrodes (class A)	Tetrodes with load distributed between anode and screen (optimum value)	Tetrodes with load distributed between anode, screen, and cathode (Q.U.A.D. arrangement)
Efficiency, %	27	38	36	36
Relative power output	1	1.4	1.35	1.35
Relative distortion just below onset of grid current	1	2	1.5	0.5
Load resistance / Output resistance	2–4	0.05–0.1	0.5–1	2

of the efficacy of damping, of the load resistance/output resistance ratio, sometimes called the damping factor, the scale of which becomes virtually meaningless at high values. It appears to be common practice to aim at as high a value as possible, with presumably infinity (zero output resistance) as the ideal. An output resistance of zero is, of course, only an arbitrary figure, which has ultimately to be added to the speech coil resistance.

Independently of the output-stage circuitry, zero—or any reasonable value positive or negative—can be obtained by a mixture of negative voltage and positive current feedback. It should be pointed out, however, that the optimum value is dependent upon the loudspeaker and particularly the intended performance of its enclosure, so that the doctrine "the more damping the better" is not always sound.

COMPARISON OF OUTPUT CIRCUITS

To summarize, Table I gives a comparison of the relative merits and demerits of various output circuits. It will be seen that there is little to choose between the performance of triodes and distributed-load tetrodes (especially the cathode-coupled variety), with the exception of efficiency, in which respect the tetrode circuits are superior to the triode.

In order to avoid misapprehension, it should be stated that a similar order of performance is obtainable from a conventional tetrode circuit, by the application of the appropriate degree of negative feedback, preferably in the form of multiple loops to ease the stability problems. The advantage of the distributed-load circuits is that, as a considerable amount of negative feedback is included in the output stage itself, the design of the remainder of the amplifier is simplified and the problems of stability and restriction of scope in design usually associated with large amounts of over-all negative feedback are avoided.

PRACTICAL DIFFICULTIES

So far we have only been considering the ideal case. In a practical transformer, however, the windings are not perfectly coupled, but are more loosely coupled by a complex network of leakage reactances formed by the distribution of leakage inductance and self-capacitance throughout the windings. This departure from the ideal may mean that, at high frequencies, the circuit is not at all as it would appear on paper, and the effective sense of the coupling may even be reversed, producing oscillation. In a less severe case, peaks and troughs in the frequency-response characteristic may occur, accompanied by "ringing" and instability when the amplifier is excited by a transient.

These defects are serious and can be avoided only by designing the output transformer carefully and by maintaining close control over its production, as even with transformers of the same nominal specification, wide variations in performance at high frequencies may occur owing to minor variations in the quality and thickness of insulants and in the positioning of windings.

The designer who has complete control over production can arrange that the materials and construction of the transformer do not depart from specification, and even if they should do so he has facilities to detect and correct the deviation at an early stage. He is therefore able to make use of circuitry of the type discussed, without the dangers which would attend its use in unskilled hands or where measurement facilities are absent. The advantages obtained have already been discussed.

The constructor with limited facilities cannot be too strongly advised to keep to proved circuits which are inherently trouble-free. In particular, he should keep to designs requiring the minimum number of coupled circuits in the output transformer, since the possibility of pitfalls is greatest in this component and increases rapidly with the number of windings when all these must be closely coupled.

It will be appreciated from the foregoing that there are a large number of solutions to the problem of designing a first-class amplifier, and no one of these solutions can be called the best solution. Each has its advantages and disadvantages, and the individual designer must choose that which most nearly meets his needs. The "goodness" of an amplifier is not shown by its circuit diagram. Circuits have no inherent magic properties, but are merely the tools with which the designer seeks to achieve a certain result, and different designers—provided always that they have the same high standards in view—may achieve the same result by different means.

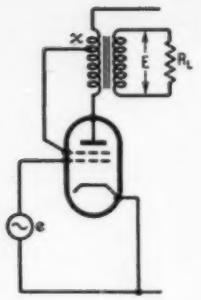
APPENDIX

Let $\mu = \dfrac{E_a}{E_g} = g_m R_a$ and $m = \dfrac{E_a}{E_g}$.

$$\therefore \frac{E_a}{E_a} = \frac{\mu}{m}$$

x = fraction of output fed to screen

E = output voltage in load R_L, produced by grid voltage e



Neglecting the effect of screen current in the load, which is normally less than 10%,

$$\text{Current in load due to } e = e\frac{\mu}{R_a + R_L}$$

$$\text{Current in load due to } xE = -xE\frac{\mu}{m(R_a + R_L)}$$

$$\therefore \text{Voltage in load} = E = \left[e\frac{\mu}{R_a + R_L} - xE\frac{\mu}{m(R_a + R_L)}\right]R_L$$

$$\therefore e\frac{\mu R_L}{R_a} = E\left(1 + x\frac{\mu R_L}{mR_a}\right)$$

$$\therefore \quad \text{Gain} = \frac{E}{e} = \frac{\dfrac{\mu R_L}{R_a + R_L}}{1 + x\dfrac{\mu}{m}\dfrac{R_L}{R_a + R_L}}$$

When $x = 0$,

$$\frac{E}{e} = \frac{\mu R_L}{R_a + R_L}$$

When $x = 1$,

$$\frac{E}{e} = \frac{\dfrac{\mu R_L}{R_a + R_L}}{1 + \dfrac{\mu}{m}\left(\dfrac{R_L}{R_a + R_L}\right)}$$

Output resistance.

Let $R_L \to \infty$, then

$$\frac{R_L}{R_a + R_L} \to 1$$

Then gain $(x = 0) = \mu$.

$$\text{Gain } (x) = \frac{\mu}{1 + x\dfrac{\mu}{m}} = \mu'$$

$$\text{Output resistance } (x = 0) = \frac{\mu}{g_m}$$

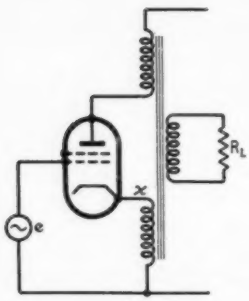
$$\text{Output resistance} = \frac{\mu'}{g_m} = \frac{\mu}{g_m\left(1 + x\dfrac{\mu}{m}\right)}$$

"Q.U.A.D." case.

Gain is given by

$$\frac{\mu\dfrac{R_L}{R_a + R_L}}{1 + x\dfrac{\mu}{m}\dfrac{R_L}{R_a + R_L}} = A$$

$$\text{Gain with feedback} = \frac{A}{1 + xA}$$



$$\text{Gain} = \frac{\dfrac{\mu\dfrac{R_L}{R_a + R_L}}{1 + x\dfrac{\mu}{m}\dfrac{R_L}{R_a + R_L}}}{1 + x\dfrac{\mu\dfrac{R_L}{R_a + R_L}}{1 + x\dfrac{\mu}{m}\dfrac{R_L}{R_a + R_L}}}$$

$$\text{Output resistance with feedback} = \frac{\text{Output resistance without feedback}}{1 + x\mu}$$

$$\text{Output resistance} = \frac{\dfrac{\mu}{g_m\left(1 + x\dfrac{\mu}{m}\right)}}{1 + x\dfrac{\mu}{1 + x\dfrac{\mu}{m}}}$$

Design of a Preamplifier for Low-Level Inputs

MARTIN V. KIEBERT, JR.

IN THE process of designing a preamplifier, equalizer, and control unit to be used with a new and outstanding low-level magnetic moving coil pickup, it was essential that an objective survey be made of all currently available commercial units in order to ascertain their advantages and disadvantages. Such a study would serve to focus attention upon the place in the high-fidelity market that a new unit should most logically fill in view of the performance of existing and available units. A new preamplifier must be technically superior and should, if possible, require a minimum of gadgetry presupposing special quasi-technical information on the part of the user. After all, the engineer's wife may also like to hear a Toscanini recording, and a device comparable in complexity to a master control room would generally tend to discourage her use of the equipment and even its acceptance in her household.

A study was made of a number of preamplifiers on the market. These units were first evaluated with regard to output noise level as referred to a nominal 1-volt open-circuit low-impedance output (generally represented by a cathode follower). Investigation and testing of the basic circuit configurations revealed a number of interesting facts.

It was universally found that the use of an ac filament supply in low-level stages was not compatible with the requirements for a low noise level unless carefully selected tubes were employed and unless the entire assembly was mounted as one unit and considerable care taken with regard to grounding, shielding of the power transformer, shielding of the filament, and current balance as obtained by means of twisted filament and power leads. The area of the input circuit loop had to be held to the absolute minimum.

It was almost universally found that the lowest noise levels were obtained in units which employed a grounded cathode and work function bias in the input stage or stages.

It is also worth while and interesting to note that the preamplifiers which had a low hum level (using work function bias and a grounded cathode) always had higher distortion as inherent in this type of circuit.[1] Conversely, the lower-distortion units which employed cathode self-bias

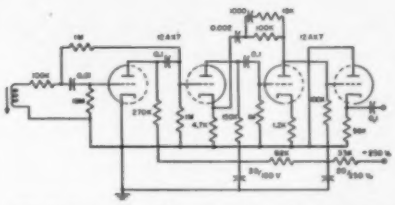


FIG. 1. Work function bias, grounded cathode preamplifier.

generally had a 6 to 10 db higher noise and hum level. The use of heavily bypassed cathodes, a device which precludes cathode feedback and equalization in the first stage, improved the hum level by 3 or 4 db.

A straightforward but slightly varied circuit technique has recently been employed to circumvent the distortion problem while still permitting work function bias and a grounded first stage cathode. Figure 1 is the schematic of such a unit. Owing to the likelihood of hum and noise pickup problems where a very low-voltage pickup or microphone is used, this particular circuit configuration should not be employed unless input levels of the order of 10 to 30 mv are available. The preamplifier system which was finally evolved required full output with a 2-mv signal and without an input transformer. The selection of an input amplifier for the subject unit was predicated upon this factor, as well as other considerations to be described.

The next factor studied was that of distortion as measured through the various preamplifiers. Again, it was almost universally observed that the manufacturer's optimism had gotten the better of him. It was possible to realize the manufacturer's sales departments' performance figures by employing a careful selection of tubes and a controlled line voltage held at a fixed level. The specific measurement figures were quite another thing when obtained with unselected tubes, such as are normally available to the user, and with a line voltage which varied over the range normally found in the home.

A third point under consideration involved the packaging and arrangement of the preamplifier for the user's optimum convenience, and the greatest probability of proper and satisfactory operation by relatively inexperienced personnel.

[1] See W. B. Bernard, Voltage Amplifiers, *Audio Eng.* (February, 1953).

In order to achieve these ends, it appeared that the environmental equalization and level control should be separated from the balance of the system and handily located at the main listening position. The preamplifier and power supply, with input switching functions, appeared logically to belong in the main unit. These components should be so constructed as to require the least amount of operator manipulation and knowledge for proper operation and equalization of the system, for the particular type of record being played, and for the particular type of program source.

The new preamplifier specification required a breakdown of the system into two broad but necessarily interrelated objectives: an electrical performance requirement, and a mechanical and layout requirement.

With regard to the first objective, it was desired that a 1-volt output should be available when a 3-mv input signal was used. Under this condition of operation, an output signal plus noise-to-noise ratio should be provided of at least 52 db when referred to 1.0 volt across the output. Intermodulation distortion was to be kept below 0.1% at a rated 1-volt output level when feeding into a 50,000-ohm capacitative load (represented by a 300-foot cable). Wide-range frequency response would be the obvious result.

The second objective was to provide a basic switching system of the simplest type possible. An eight-position five-deck unit was used, which (as will be noted in Fig. 2) provides for the selection of the proper input circuit and simultaneously performs equalizer functions in the low-level preamplifier and recording equalizing amplifier. In addition, it selects the optimum output level of the preamplifier with various input levels as is typical of Fairchild, General Electric, Pickering, Clarkstan, and similar magnetic pickups.

A second switch located in the same assembly provides for simultaneous recording characteristic equalization of both high and low frequencies, resulting in optimum compensation for AES, NAB, LP, ORTHRO, and most 78-rpm characteristics. Misadjustment of this control, however, has a negligible effect on performance of the system, and no measurable effect if the environmental equalization is properly employed. It is apparent that far too much attention has been and is being paid to many of these relatively minor equalization details by high-fidelity enthusiasts, who debate over the question of a 1- or 2-db shift caused by a change in turnover frequency. A difference of ± 3 db, if the information of Fletcher and Munson is correct, can never be noticed in a complex musical sound. In a recent Society of Motion Picture and Television Engineers Symposium on stereophonic sound, Dr. Fletcher reaffirmed this point.

It is common knowledge that most loudspeaker systems have a considerably greater variation in their frequency-amplitude characteristics, with relatively large changes in level, over their "plateau region" of 1 to 5 octaves. This fact and the limited importance of recording characteristic

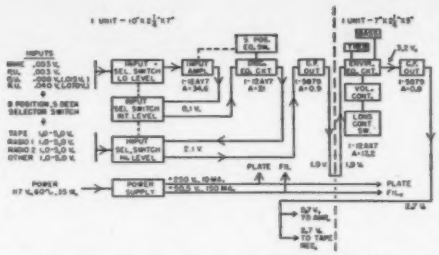


FIG. 2. Functional block diagram of Kiebert high-quality preamplifier.

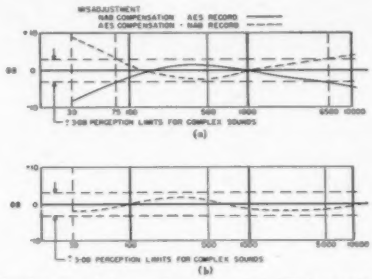


FIG. 3. Environmental equalization. (a) Flat position. (b) Optimum setting.

equalization make a considerable amount of discussion on the "exact" equalization curve somewhat academic. Figure 3a indicates what occurs when the turnover is improperly set. Figure 3b shows what may be done under these circumstances by a touch of the environmental equalization controls. It is believed desirable, however, to provide low-frequency and suitable high-frequency compensation so that a properly made recording can come through "flat" when the environmental equalizer is in the "flat" position and the loudness control operated only as a volume control.

In formulating the basic design of the new preamplifier, it was envisioned that a second unit remotely located at any convenient point up to approximately 300 feet would require only a six-conductor interconnecting cable. The extension unit should have bass and treble environmental equalization, a volume control, plus a three-position switch. This would permit the use of a level control straddling the fence to perform the following functions:

1. Volume control alone.
2. Loudness control with bass compensation.
3. Loudness control with both bass and treble compensation.

Loudness contours of the Fletcher-Munson curves should be examined with regard to their derivatives as a function of level and frequency. When this is done, it is immediately apparent that in the high-frequency end of the spectrum the derivatives are approximately constant. An entirely different set of circumstances exists in the low-

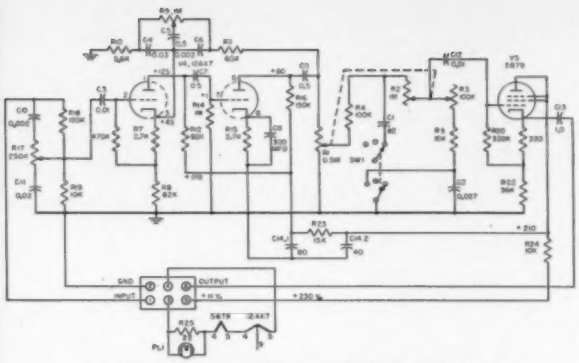


FIG. 4. Environmental equalization circuit.

frequency end of the spectrum, where the derivatives vary quite markedly as a function of level and frequency. In the writer's belief, this indicates that bass equalization is desirable in the level control—provided, of course, that it is properly utilized.

The environmental equalization in the new preamplifier provides for bass boost or attenuation of 16 db at 100 cps, and treble boost or attenuation of approximately 20 db at 15,000 cps.

The design of the specific unit described by the circuit of Fig. 4 provides a frequency response flat to within ± 0.1 db over a range of 50 to 15,000 cps when the environmental equalization controls are in the "flat" position. Under this condition of operation, approximately 20 db or more of feedback is employed in each unit section, the preamplifier, the recording characteristic equalizing amplifier, and the bass equalizer section. Excellent frequency noise and distortion stability are maintained when tubes are changed and when the unit is operated over relatively wide ranges of line voltage (105 to 135 volts).

It appears desirable that all preamplifier and amplifier systems roll off the bass as fast as possible below the point where the speaker system is "clean" and provides a useful output level. This factor has been overlooked in most designs. Considerable effort has often been expended to provide excellent low-frequency response in the amplifier system, whereas in actuality the speaker system could not utilize these low-frequency components. The inclusion of very low-frequency signal components, requiring operation of the speaker over its most nonlinear ranges of displacement, often actually causes the speaker performance to deteriorate and increases the Doppler distortion in the speaker system. Power line transients previously mentioned, as well as turntable rumble, also occur in the low-frequency region and give rise to speaker nonlinearity.

In an optimum system, it would appear desirable to employ a high-pass filter with a relatively sharp cutoff below approximately 40 cps. Such a filter would necessitate expensive coils employed at circuit levels and positions susceptible to hum pickup. "Ringing" and transient difficulties might also be encountered. A more straightforward design is available through the selection of proper RC coupling circuits so that suitable rolloff starts in the range of 40 to 60 cps.

The specific rolloff point may be readily shifted as judgment dictates. The use of an external, low-frequency (resistance-capacitance) type rejection network which puts a "hole" in the curve in the region of 5 to 15 cps will further aid in minimizing undesired low-frequency transient due to turntable rumble or power line bumps. Typical of such a circuit is that of Fig. 5.

Aside from the foregoing general problems, there are a number of practical design considerations that are all too often overlooked—or at least not reported on—with the consequence that each design engineer must rediscover these fine points for himself.

It is particularly significant that the power supply is not a "battery eliminator." As a result, the line transients normally encountered in all power circuits come through the system with "pops" and "thumps." Even with low-frequency interstage cutoff networks, these transient surges

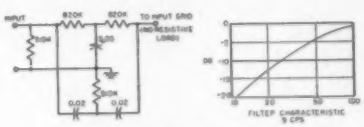


FIG. 5. Rumble filter.

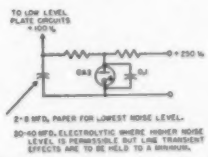


FIG. 6. Optimum low-level plate decoupling circuit.

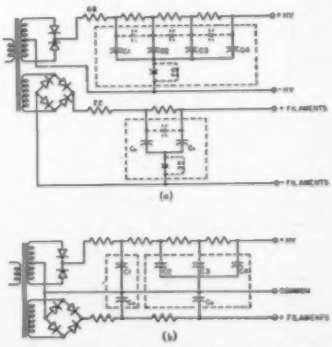


FIG. 7. Typical power supply. (a) Plate and filament circuits. (b) Optimum layout.

TABLE I. Cathode Follower Test
(½ section each tube; optimum E_g each case)

Tube	E_{bb}, volts	I_p, ma	R_K, kΩ	E_g, volts	IM,* %
12AU7	200	1.99	1.5 K	7	0.71
	200	1.96	1.4	4	0.295
	200	1.97	1.6	2	0.09
	250	2.52	1.42	7	0.44
	250	2.47	1.6	4	0.19
	250	2.31	2.0	3	0.06
	300	2.95	1.65	7	0.32
	300	2.82	1.9	4	0.12
	300	2.78	2.0	2	0.05
12AT7	300	3.5	0	7	0.06
	300	3.5	0	4	0.01
	300	3.5	0	2	0.01
12AX7	300	1.96	280	7	0.01
	300	1.89	315	4	0.01
	300	1.46	770	2	0.01
12AY7	200	1.97	60	7	0.065
	200	2.01	155	4	0.005
	200	1.98	245	2	0.005
5879 (Triode con.)	250	3.03	200	7	0.08
	250	3.07	235	4	0.005
	250	3.05	280	2	0.002
5687	300	3.72	1.14 K	7	0.05

* The indicated IM was that obtained by subtracting a measured residual IM of 0.1% from the value obtained through the circuit of Fig. 8. This technique is open to question but is presented in this way in order to provide a cross reference to other published information which followed this approach.

in plate voltage may give rise to additional and varying intermodulation distortion, which becomes apparent in the middle of the transmission band. A gas regulator tube in the plate supply line to low-level stages, as well as the avoidance of dc-coupled low-level stages and cathode followers, is a material aid in overcoming these difficulties.

On the lowest level, decoupling and isolation circuits similar to those shown in Fig. 6 provide for optimum operation. If possible, the decoupling condenser should be a high-quality paper condenser; an electrolytic unit in this application will often increase the noise level by 3 to 6 db.

A typical power supply and filter system is shown in Fig. 7. C_a and C_b are often located in one common unit, with C_1, C_2, C_3, and C_4 in a second unit. Unfortunately, this is not good design because the capacitor manufacturer puts in an undesirable extra component or two, as shown in Fig. 7 by the dotted lines of the actual equivalent circuit. These components are intrinsic to the construction of multiple-section electrolytic condensers. The location of C_a and C_1 in the same case, with C_b, C_2, C_3, and C_4 in another case, is a good way to circumvent this difficulty, as shown in Fig. 7b.

As previously pointed out,[2] proper component selection is important in minimizing noise and distortion in feedback circuits. This fact has been considered in designing the subject preamplifier. The limitations of conventional voltage amplifier tubes, both with and without feedback, have been well defined by W. B. Bernard.[1] No specific information was available to the writer as to the performance of cathode followers. Accordingly, a series of studies was made in order to evaluate the optimum operating conditions for a number of types of tube, and for a number of tubes in each class. Figure 8 represents the test circuit. The results are summarized in Table I.

As a next step, functional design studies were made of each fundamental circuit component and assembly in terms of the manner in which the user could operate the system for optimum performance. After a large number of possible arrangements were sketched, some conclusions appeared to be in order (see Fig. 9):

1. Level and environmental equalization should be under the control of the listener at his normal listening position.

2. Recording characteristic compensation control should be at the turntable position.

3. The input selector switch should be close to the input sources in order to reduce cabling to a minimum. All input sources should be as close together as possible for the same reason.

Low-level leads should be as short as possible. Only leads of comparable level should be in the same cable. Cabling should be capable of providing electrostatic shielding between input and output circuits.

The arrangement seen in Fig. 9 (A system) is fairly satisfactory, provided that the normal listening position is conveniently close to the equipment position. If the listening position is toward the center of the room, certain difficulties are obvious.

From the standpoint of the convenience and enjoyment of the user, the layout of Fig. 9 (E system) appears to be an optimum starting point with all factors considered. This configuration provides level control and environmental equalization where needed and requires the use of but one small six-conductor cable which need not be shielded, owing to the relatively high signal levels fed into and coming out of the remote unit. In addition, installations such as those shown in Fig. 9 (A and D systems) may be readily achieved merely by mounting the extension unit alongside the main unit.

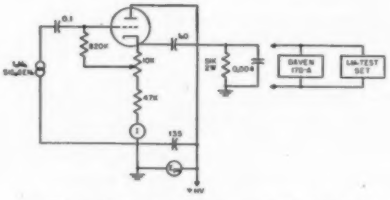


FIG. 8. Cathode follower—test circuit.

[2] M. V. Kiebert, Jr., The "Williamson Type" Amplifier Brought Up To Date, *Audio Eng.* (August, 1952); A Preamplifier Switching and Equalizing Unit for Critical Listening, *ibid.* (September, 1952).

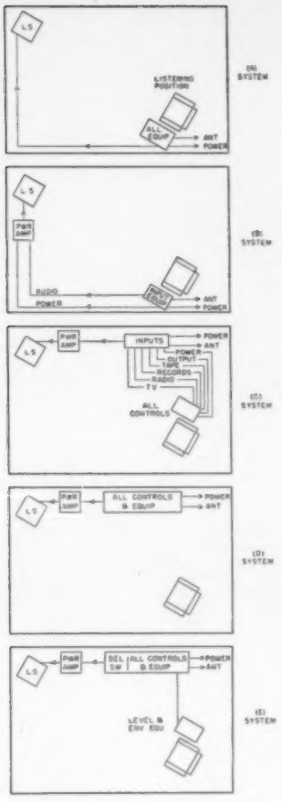


FIG. 9. Functional layouts.

Types of inputs, falling into two general classes, were next to be considered. The low-level group should provide sufficient gain with a good signal-to-noise ratio for the following inputs:

1. Microphone, 0.002 to 0.004 volt.
2. Low-level pickup of the dynamic type, 0.003 volt.
3. Medium-level magnetic pickup, 0.01 to 0.02 volt.
4. High-level magnetic pickup, 0.04 to 0.07 volt.

Inputs of the high-level group are normally fed from equipment designed to provide 1 to 2 volts at a relatively low impedance. Signal levels in this class have generally been designed to feed into a power amplifier at about the 1-volt level and therefore do not require subsequent amplification. However, there is often a need for additional equalization of these signals after selection of the inputs and prior to the output stage. In accordance with this requirement, provision was made for equalization which is likely to be different in such applications as feeding a tape recorder as compared to environmental equalization for listening. Typical inputs of the high-level group are as follows:

1. Tape recorder output.
2. FM receiver output.
3. AM receiver output.
4. Television receiver output.

In consideration of the recording characteristic compensation, it appeared that at least four low-frequency and four high-frequency curves would be required.

The controls of the subject preamplifier may be enumerated as follows:

1. An "on-off" switch and pilot light.
2. A level control.
3. A three-position selector switch for compensation of the level control.
4. An input selector switch.
5. A low-frequency recording characteristic compensation switch.
6. A high-frequency recording characteristic compensation switch.
7. A bass boost or attenuation control.
8. A treble boost or attenuation control.

This is a formidable array of gadgets. In view of the fact that most radio receivers have only two to four or five controls which generally function in a yes or no manner—that is, one either hears the station or does not—the owner of home entertainment equipment often is not accustomed to the fine nuances of a high-fidelity system. Accordingly, careful design consideration was given to the layout, use, and function of each of the controls.

Where possible, it is of advantage to combine functions, as in the frequently used device of integrating the power switch of a radio with its "tone" or volume control. However, considerable care must be exercised with low-level high-gain units to avoid undesirable couplings, which may occur when high-impedance high-gain circuit units are placed in close proximity to power and high-level circuits. This represented one disadvantage in combining the power switch with other controls in the subject unit. Other reasons for not making the power switch part of the input selector switch were the likelihood of induced ac hum due to the relatively large ac current circulation, and the relatively short switch life made inevitable by the necessity of going through at least a portion of the switch cycle each time the unit is turned on and off.

Although the input selector switch is self-explanatory, several design points should be underlined. Static drain and charging resistors should always be employed to avoid "pops" and "thumps" when changing levels and positions, and the switch should provide a "flat" equalizing position for a low-level microphone. Arrangements should be made for maintaining the same relative input level to the recording characteristic equalization circuit regardless of the output level of the particular high-fidelity pickup employed. The latter requirement is particularly important when a "loudness" control is used.

Pilot lights were dc-operated. In the remote unit, this removed the need for ac circuits in the extension cable. In the main unit, the dc pilot light serves a dual function—as part of the dc filter for the filament string, and as an excellent continuity indicator for the same circuit.

The controls may be divided into two subgroups. The first consists of controls which should always be under the direct control of the listener and so adjusted as to provide him with a signal resulting in maximum enjoyment in terms of his listening environment and circumstances. In this group are the level and/or loudness control and the bass and treble environmental equalization controls. It is the writer's hope that high-fidelity enthusiasts will someday become sufficiently uninhibited to set these controls to a point where the program pleases them, rather than to some number on an indicator which another enthusiast (with an entirely different system operated in a thoroughly different environment) has recommended.

The second group of controls logically includes the power switch, input selector, tape recorder, receivers, turntable, etc. It is equally logical, under this arrangement, to locate the recording characteristic compensation switch so that, when a record is placed on the turntable, the switch may be set to its predicted optimum position. Extensive testing and investigation indicates that it is practicable and desirable to combine the high-frequency and low-frequency compensation in one switch. This is particularly true where satisfactory environmental controls are available and where the listener uses them to produce the results he likes at that particular time! Figures 3a and 3b illustrate this point.

Several comments should be made with reference to the selection of specific circuits and components. In order to conserve space, miniature tubes were employed, but subminiature tubes were avoided because of the socket problem in servicing. Even with miniature tubes, the socket contacts and the relatively small tube pins present a noise problem. Silver-plated beryllium socket contacts should be used.

In the selection of tubes, 12AY7's were employed for the low-level stages in view of their superior noise characteristics. Additional devices for minimizing noise include a slightly lowered filament voltage, selection of an optimum bias providing a fairly high mutual conductance, the use of wirewound resistors in the input stage grid, cathode and plate circuits, and dc filaments. The noise level was held within 5 to 7 db of its theoretical value, an improvement of about 10 to 12 db over the majority of commercial units.

In order to keep intermodulation distortion from exceeding reasonable levels, it was essential that the operating stages (other than the cathode followers) be held to output levels under 2 or 3 volts. Even at these levels, at least 20 db of feedback in the system was essential. It is particularly fortuitous that, owing to the intrinsic characteristic of the amplitude-frequency curve of feedback equalizer circuits

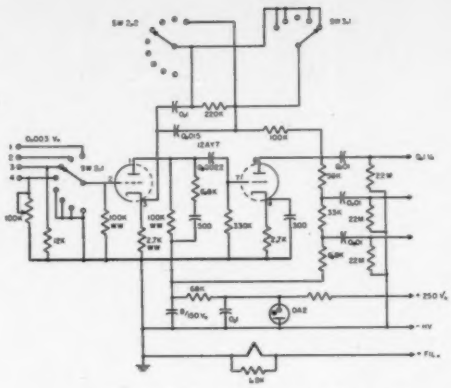


FIG. 10. Input stage, 12AY7.

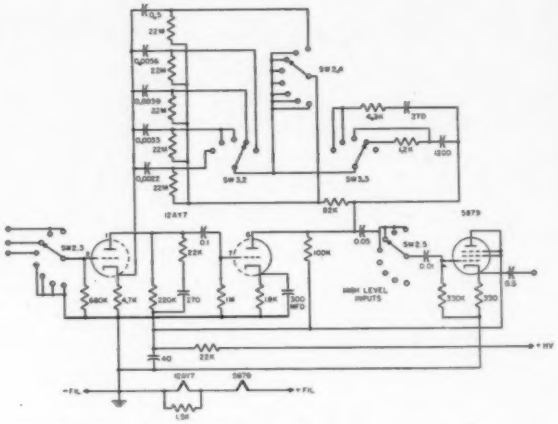


FIG. 11. Recording characteristic equalization stage—C.F. out.

with low-frequency boost, the IM remains at a low level. Full advantage was taken of this phenomenon in each of the equalization stages employed.

Figure 10 represents the low-level input stage. It will be noted that the extra-low frequency boost required for proper AES compensation is added in this stage by the 0.015-mf condenser shunted by the 0.1-mf condenser in series with a 220,000-ohm resistor employed in the feedback loop. The characteristics of this network combined with the selected values of the interstage coupling components provide a peak of approximately 6 db at 60 cps, after which a relatively fast rolloff is accomplished. This rolloff helps minimize turntable "rumble" and the effects of line transients. The use of feedback in this stage helps to stabilize gain and insure consistent performance even when tubes of widely varying characteristics are employed. The overload level is at 6 volts, where the IM reaches about 0.2%. The normal output operating level, with Fairchild or General Electric magnetic cartridges, is in the range of 0.1 to 0.3 volt. Accordingly,

an ample margin is provided between the normal level and the overload point.

Figure 11 covers the section of the circuit which provides the necessary equalization for the various types of recording characteristics. An increased amount of feedback is utilized at this point, with consequent improvement in the overload characteristic. The overload level in the recording characteristic compensation circuit is approximately 10 volts, the normal input level about 0.1 volt, and the normal output level about 2.1 volts. A 12AY7 tube is again used in the interest of maintaining the best possible signal-to-noise ratio. Because of the higher available input levels, wire-wound resistors are not needed.

Figure 4 represents the environmental equalization circuit. In order to keep input and output at about the same level, a "losser"-type high-frequency adjustable equalization circuit is employed, with low-frequency compensation achieved through the use of feedback. The input is again at a relatively low level, about 0.2 volt. The output level is at about 3 volts which, when compared to the overload point of approximately 12 volts, provides an ample margin on the distortion encountered at the working level. The use of a large amount of negative feedback at all equalizer settings, and the further increase in the amount of feedback employed when low-frequency attenuation is used, materially helps to keep the IM distortion at a very low level under this most difficult operating condition. This is a feature not found in other systems.

When constructing and assembling this system, in view of the inherent nature of the high-grain wide-band circuits employed, consideration and care must be exercised to avoid stray couplings. The placement and arrangement of circuit components is critical.

Transient studies with a square wave signal and careful

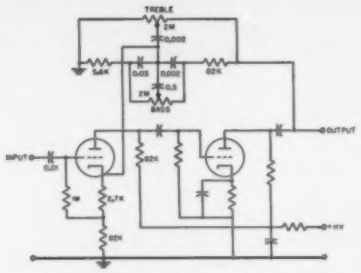


FIG. 12. Feedback bass and treble environmental equalization circuit.

IM studies have proved the soundness of the subject design. No "ringing" occurs at any operating adjustment, and properly integrated and differentiated wave forms are obtained when and where desired. The IM at normal output levels of 1 to 2 volts appears to be in the range of 0.1 to 0.2%. Because these values are at threshold levels for most IM measuring equipment, the actual IM may be lower. Additional tests indicate that the IM is under 0.6% at a 5-volt output level and that both distortion and gain are essentially independent of input line voltage over a range of 100 to 135 volts with the design center at 117 volts.

A modification of the environmental equalization system of Fig. 4 has been devised such that both bass and treble compensation are obtained by feedback. The circuit is shown in Fig. 12. Use of this circuit does require care, however, in order to keep down deleterious effects from undesired stray couplings and common impedance coupling difficulty through the plate supply circuit. Use of this circuit in lieu of that in Fig. 4 provides about 20 db more system gain inasmuch as it avoids the loss of the conventional RC "losser"-type treble equalization circuit frequently employed.

A New Program Distribution System

STEPHEN F. TEMMER* AND REIN NARMA†
Gotham Recording Corporation, New York, New York

PLANNING a system layout of a major sound installation, whether it be for purposes of broadcasting, recording, public address, or any other application dealing with the distribution of many circuits to many other circuits, has for some time been a science occupying the minds of some highly specialized engineers in the audio-electronics industry. Many systems have been designed and built over the years, from installations such as a major broadcasting network might boast, to small "package" systems intended for smaller applications. This article deals with a fairly extensive distribution network for use in a recording installation requiring the receiving and sending of signal over a multitude of circuits.

PRESENTLY USED SYSTEMS

The matter of program distribution is most commonly handled through the use of a 150- or 600-ohm terminated trunk or "bus," as we shall refer to it hereafter, which is bridged at various points by a high-impedance device. In this way no additional termination of any magnitude is placed across the bus, and its level does not drop even with several bridged feeds across it. The bridging impedance used in most applications is of the order of 10,000 ohms or higher, so that if less than twenty bridges are placed across a 600-ohm bus, their combined impedances will equal 600 ohms. This termination in parallel with the existing 600 ohms termination will cause the level on the bus to drop approximately 4 db, depending on the internal impedance of the amplifier feeding it. The loss incurred in an average bridging circuit is about 22 db, under the best turns-ratio-gain conditions of a bridging transformer. This loss must, of course, be made up by subsequent amplification, if the final level required is the same as the bus level itself.

Owing to the necessity of metering the bus program level on a standard volume-indicating meter, the bus level is invariably chosen to be 0 dbm (0.001 watt) or above. VU meter matching pads commercially available make +4 or +8 dbm the most popular levels, especially since the recommended telephone program line level is +8 dbm. Consequently, available broadcast line amplifiers are engineered to deliver +18 dbm (leaving a safety zone for instantaneous program peaks of 10 db above program level) within FCC specified distortion limits. The use of higher output level equipment has up to now been discouraged, since power amplifiers of low distortion ratings were either unavailable to broadcasters or were prohibitive in size, power consumption, and heat dissipation.

It may be prudent to note at this point that the metering of a 600-ohm terminated program line at a level of 0 dbm by a standard VU meter (properly bridged) produces 0.3% rms harmonic distortion at full-scale deflection and even more at lower readings. This is due to the partial rectification of the signal by the meter rectifier. The authors have noted many installations where not one but numerous VU meters were placed across the same program bus at various points, and we wonder whether the facts above should not be carefully considered before subsequent system layouts are designed. Perhaps this may even be the time for manufacturers to release more sensitive volume meters, now that we have entered upon an era when 0.3% distortion becomes more than just a matter of academic interest.

METHODS OF CIRCUIT SELECTION

Typical installations in the broadcast field today find radio lines, recording machines, transmitters, and the like connected to the proper program sources by means of either jacks and patch cords, push-buttons, rotary switches, or lever keys. All these methods require either the necessity of bringing all the available circuits to each recording machine, or the constant attention and attendance of an engineer-operator in a central master control room, who will patch up each feed as required when so requested by telephone or intercommunication system.

THE PROBLEM AT HAND

The system outlined in this article was designed to satisfy the following stipulations: to distribute any one of 50 in-

* Vice President, Chief Engineer.
† Research and Development Engineer.

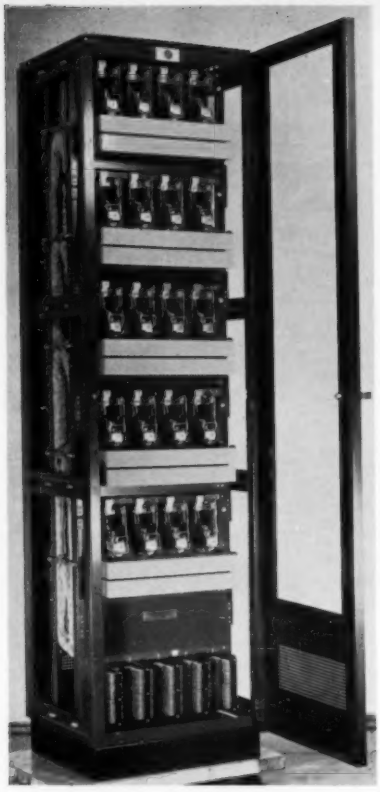


FIG. 1

coming signals consisting of radio lines, studios, tuners, turntables, tape machines, etc., to over 25 recording machines, tape, disk, and film; to make available to key executive personnel at their respective desks all these circuits for monitoring; to allow for practical expansion of facilities in the future, without making present installations obsolete; to facilitate moving of equipment to new locations with the least effort and interruption of operation; to provide adequate master control supervision of all circuits; to centralize all amplifying equipment (except for that directly associated with each recording machine) in one location; to provide the utmost protection from equipment failures.

THE SWITCHING OF CIRCUITS

The actual wiring of each of the more than 25 machines, located in twelve separate rooms over a widespread area, with 50 possible program sources would be prohibitive in cost as well as cumbersome to handle. At the same time the dangers of human error make the master control patched system far from satisfactory. Aside from this, experience with contact-type switching devices has shown that they require periodic burnishing of their contacts, which would become difficult in a widespread system. The system selected consists of a single, broadcast-type, 7-foot rack, into which 40 Strowger stepping selectors are fitted (Fig. 1). These steppers are actuated by telephone dials located on each recording device and permit access to 49 lines, yet require only a single pair of wires to each location. At the same time maintenance is concentrated in a single, easily accessible location.

THE BUS AMPLIFIER

Careful research into available amplifying equipment convinced us that to suit our special needs we would have to build our own. The amplifier had to be small enough to permit the installation of 49 units in a single rack and yet deliver sufficient power to permit the simultaneous recording on all machines at the same time and from the same circuit. In a concentrated effort to eliminate high-impedance bridging, it was decided to operate at an impedance low enough so that a 600-ohm termination would effectively bridge the bus. A 20:1 bridging ratio was found to be sufficient in view of the excellent damping factor of the proposed amplifier. This bridging ratio resulted in the 30-ohm bus which has become standard for our system. The actual level at which the bus was to operate was determined by calculating the needs of the recording equipment and then going backward through the circuit to the bus (Fig. 2). The input of most recording equipment is +4 dbm or above, which permits the use of a VU meter at this point. The loss of the input fader (600-ohm balanced ladder) was found to be 10 db for an average setting of three o'clock, which meant that an effective 600-ohm line level of +14 dbm was needed at each machine for proper input. The loss due to the 20:1 impedance mismatch comes to 13 db, which determines the final level of the 30-ohm bus at +27 dbm (0.5 watt). The fact should be noted that dial selectors located on each executive's desk are equipped solely with a 600-ohm to voice coil transformer, which will deliver sufficient power to a small desk-type speaker unit for instantaneous program feed monitoring without requiring any amplification locally. This is true where the amplifier is used as a bus amplifier and therefore must be bridged. The same am-

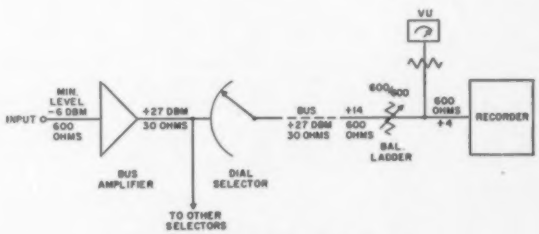


FIG. 2. Block schematic of system.

plifier will deliver 15 watts at 7½ ohms (connecting the output windings parallel) which is more than adequate for common loudspeaker monitoring requirements.

The physical size of each unit (Fig. 3) is 2½ in. wide, 5 in. high, and 13 in. long. This permits the mounting of seven amplifiers on each shelf, and seven shelves, one above the other, in a 77-in. rack panel space with plenty of room left over for terminal blocks at the bottom. Electrically, the amplifier consists of two separate and distinct, single-ended amplifier channels acting as "Siamese twins." They have a common input and output transformer. Each chain consists of one 12AU7 having its two elements cascaded, followed by a single-ended 6V6GT. This chain, together with the opposite, or "Siamese" chain, forms a regular push-pull amplifier. The input tubes are joined by a standard input transformer of sufficiently high operating level, so as to

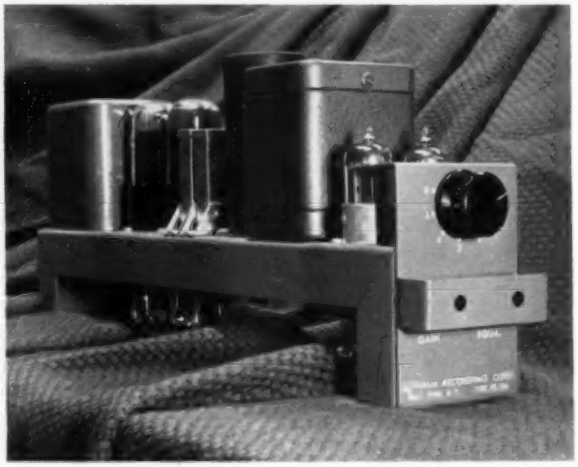


FIG. 3

hold distortion to a minimum at this point. The output tubes terminate in a specially wound transformer having four separate primaries of equal impedance and a split and balanced secondary of 30 ohms. The driver stage is joined by a common cathode resistor which tends to offset any ac unbalance resulting from uneven tube aging (Fig. 4). Also included in the circuit is a high-frequency equalizer capable of a boost of 18 db at 15 kc, to offset losses due to long-distance telephone transmission lines. Through the use of considerable feedback (both negative and positive) it has been possible to largely offset the possible loss of program feed resulting from failure of any tube or any component associated with a particular stage. The maintenance of level through such a failure was considered of utmost importance. Under the amplifier's normal operating conditions, tube aging is to be encountered most rarely. A 6-position switch on each unit connects with a master tube meter which is checked at the start of each day and which

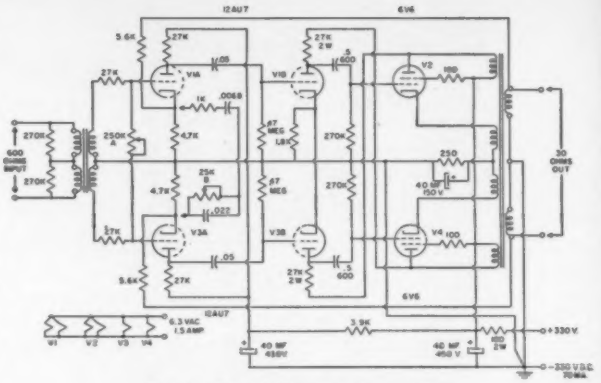


FIG. 4. Circuit diagram of amplifier.

shows such aging before any ill effects may occur. Tube failure, however, is unpredictable. Table I illustrates

TABLE I

Failure	Change in level	IM dist. at +27 dbm	Max. power output below 3% IM, dbm
None	None	0.05%	+43
V-1a or V-3a	None	0.10%	+40
V-1b or V-3b	None	0.10%	+40
V-1a and V-1b	None	0.25%	+40
V-3a and V-3b	None	0.25%	+40
V-2 or V-4	None	0.35%	+37
V-1a, V-1b & V-2	None	0.40%	+36
V-3a, V-3b & V-4	None	0.40%	+36
V-2 and V-4	−6 db	1.50%*	+22

* 1.5% measured at +21 dbm.

the effect on the gain of the bus amplifier as well as its distortion, resulting from the failure of its various tubes. As is visible in Fig. 5, turret-type tube sockets are used throughout, allowing elimination of the sides of the chassis which results in better ventilation of the output stage. Two 0.5-mf bathtub coupling condensers between the driver and

FIG. 5

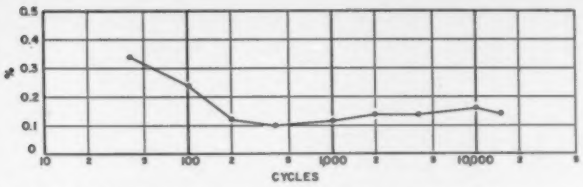


FIG. 6. Level of rms harmonic distortion at 10 db above program level. Measurements were made at +37 dbm (5 watts).

output stages are mounted on fiber washers to isolate them from chassis ground. This considerably reduces distortion at high frequencies produced by 600 $\mu\mu$f leakage capacitance between the condenser element and the condenser can, which is found in most units of this type. A 16-contact connector mates with a similar socket on the rack shelf. The power supply for this rack is located remotely in the power room and consists of a three-phase power transformer and bridge-type selenium rectifier which delivers approximately 4 amp at 330 volts dc. A ripple of 0.04% was found sufficiently low for an output noise level of −56 dbm (an equivalent signal-to-noise ratio of over 70 db). Filaments are AC heated, with 75 amps at 6.3 volt needed for the entire rack. Should our readers be skeptical about the seemingly high cost of such a supply, may we add that the total cost is about $3.00 per bus amplifier.

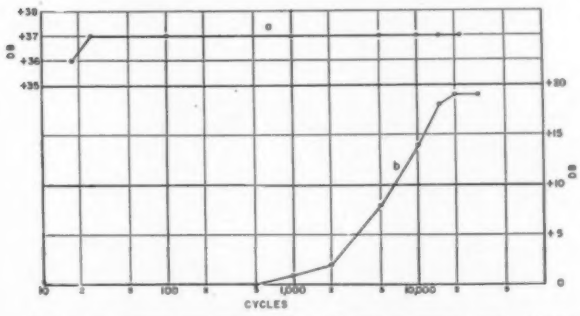


FIG. 7. a. Power response at 10 db above program level. Note: Response is flat ±½ db from 10 to 30,000 cps at +27 dbm. (b) Telephone line equalization at position of maximum high-frequency boost.

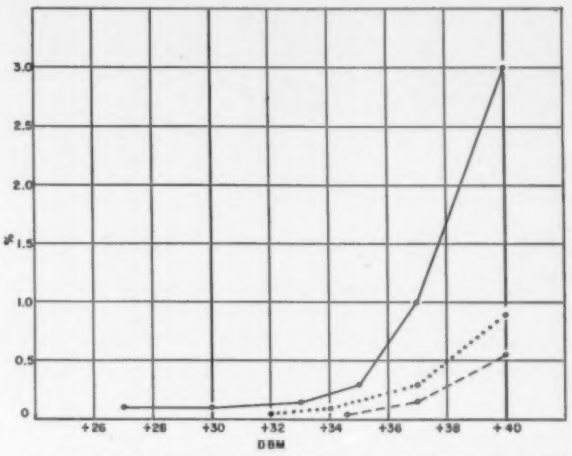


FIG. 8. Intermodulation distortion between a 60-cps and a 7000-cps signal having amplitudes in the ratio 4:1.
– – – – – – with two inputs across the bus
. . . . . with ten inputs across the bus
———— with twenty inputs across the bus

Figures 6, 7, and 8 illustrate several characteristic performance curves taken from a random production unit using a General Radio type 1932-A distortion and noise meter and type 1301-A low-distortion oscillator. In all cases the residual distortion of the test equipment has been deducted from the results shown.

We feel that the time has now come when power can be achieved without prohibitive size, making the high-level bus operation described possible, and more than that, advantageous. It permits, through the use of a single type of amplifier, the attainment of sufficient power, so that the total of all the loss devices that follow will return the signal to its required level. At no time is it necessary to dip back into the low-level regions in which hum, noise, microphonics, and crosstalk are a continuous hindrance to noise-free reproduction.

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ALFRED JORYSZ
Presto Recording Corporation, New York, New York

The following bibliography on disk recording covers the period from 1921 to 1947. As originally published it was in chronological form. To this has been added an alphabetical list arranged by authors. In both lists a brief abstract of the article is included. This bibliography is the first of four which the *Journal* plans to publish. The others will include a disk recording bibliography covering papers published between 1947 and the present, and bibliographies on tape recording and stereophonic recording and transmission.

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B. Ephraim, Increasing Disk Recording Playing Time, *Electronics*, **8**, 380 (October, 1935). A system in which the turntable speed is electronically decreased during recording and playback near the outside of the record. Linear groove speed is thus maintained approximately constant.

V. Williams, Recording Waxes, *Ind. Chemist*, **11**, 400-401 (October, 1935). Chemical composition and physical properties of recording waxes and their use in making masters.

R. R. Scoville, A Portable Flutter-Measuring Instrument, *J. Soc. Motion Picture Engrs.*, **25**, 416-422 (November, 1935). An instrument measuring the uniformity of recording and reproducing turntable speeds.

T. E. Shea, **W. A. MacNair**, and **V. Subrizi**, Flutter in Sound Records, *J. Soc. Motion Picture Engrs.*, **25**, 403-415 (November, 1935). Effect of frequency modulation of a sound signal due to nonuniform recording or reproducing speed. Physiological effects and artificial means of creating flutter.

C. M. Sinnett, Practical Volume Expansion, *Electronics*, **8**, 428-430, 446 (November, 1935). Considerably improved phonograph reproduction is obtained through automatic extension of the volume range.

Single-Phase Induction Motors for Phonograph Turntable Drives, *Elektrotech. Z.*, **56**, 1254-1256 (November, 1935). Comparison of the design data and characteristics of various European induction motors.

1936

G. J. Saliba, High-Fidelity Instantaneous Recording, *Communications*, **16**, 11-13 (January, 1936). Recording techniques using disks with cellulose coatings. High-frequency response depends on relation between radius or curvature of modulated groove and playback stylus tip. Details of cutting-head feed arrangement and a complete portable recorder.

J. P. Taylor, High-Fidelity Transcription Equipment, *Communications*, **16**, 5-8 (March, 1936).

E. W. Kellogg and **A. R. Morgan**, Measurement of Speed Fluctuations in Sound Recording and Reproducing Equipment, *J. Acoust. Soc. Amer.*, **7**, 271-280 (April, 1936). An improved "wow-meter" which uses a specially built toothed steel wheel generating an electric current. A circuit responsive to frequency changes of this current and a galvanometer which records the changes complete the instrument.

Low Noise Recording, *Electronics*, **9**, 28 (April, 1936). A new process using an extremely fine-grain material which is softened temporarily before recording. Result is a 15-db improvement in noise level.

W. N. Weeden, A Mass-less Pickup, *Electronics*, **9**, 36-38 (May, 1936). Widened frequency range is obtained by reduction of armature mass and an improved magnetic circuit. Simultaneously record life is increased and the noise level lowered.

L. B. Hallman, Jr., Practical Volume Compression, *Electronics*, **9**, 15-17, 42 (June, 1936). New automatic volume compressor without cutoff on peaks and low distortion.

E. P. Irany, New Synthetic Resins in Manufacture of Gramophone Records, *Can. Chem. Met.*, **20**, 193-195 (June, 1936). Requirements for gramophone records and some of the new resins used.

E. A. Ollard, Gramophone Record Matrices, *Metal Ind. (London)*, **49**, 165-169 (August, 1936); 239-242, 265-266 (September, 1936). Electroplating process used in manufacturing matrices.

Sound on Disks, *Electronics*, **9**, 6-10, 48, 50 (October, 1936). New recording materials, new equipment, and new techniques which give results almost equal to the original studio pickup.

1937

R. P. Glover, A Record-Saving Pickup, *Electronics*, **10**, 31-32 (February, 1937). A reduction of the change in tracking angle, as needle moves from center to edge, is claimed to minimize record wear considerably.

Multi-Unit Phonograph for Schools, *Electronics*, **10**, 42, 44 (February, 1937). A system using a number of turntables supplying a bank of headphones simultaneously.

J. R. Bird and **C. M. Chorpening**, The Offset Head Crystal Pickup, *Radio Eng.*, **17**, 16-18 (March, 1937). Principles underlying a method of avoiding tracking distortion in a new type of pickup arm.

G. J. Saliba, Instantaneous Recording Head, *Communications*, **17**, 8-9, 16, 25 (March, 1937). Features of a new cutting head include special armature construction, low operating level, and high sensitivity expressed by the modulation of a 112 lines per inch cut.

A. C. Keller, Direct Recording and Reproducing Materials for Disk Recordings, *J. Soc. Motion Picture Engrs.*, **28**, 411-426 (April, 1937). Materials available for direct disk recording classified chemically in five groups, and measurements of frequency characteristics, surface noise, life, and distortion. Data for both lateral and vertical recording.

E. W. Kellogg, A Review of the Quest for Constant Speed, *J. Soc. Motion Picture Engrs.*, **28**, 337-376 (April, 1937). Importance of constant record speed. Brief descriptions and discussions of a number of ingenious arrangements for improving speed constancy, some applicable to turntables, some to film drives.

F. W. Stellwagen, Performance of a Direct Lateral Recording System, *Communications*, **17**, 12-14, 27 (July, 1937). Data, curves, and over-all performance of complete recording and reproducing systems.

T. L. Dowey, Disk Recording, Part 1, *Communications*, **17**, 11-12, 68, 70 (September, 1937). Acoustic requirements for a recording studio and setups for making electrical transcriptions.

T. L. Dowey, Disk Recording, Part 2, *Communications*, **17**, 17-19, 58 (October, 1937). High-quality recording and reproducing equipment and advantages of vertical recording.

T. L. Dowey, Disk Recording, Part 3, *Communications*, **17**,

24-32 (November, 1937). Different steps in the production of pressings starting from a master record.

C. J. LeBel, Quality in Disk Reproduction, *Electronics*, **10**, 25-27, 77 (October, 1937). Turntables and pickups and suggestions for improvement in reproducing systems given.

M. De Toro, Distortion in the Reproduction of Hill-and-Dale Recording, *J. Soc. Motion Picture Engrs.*, **29**, 493-509 (November, 1937). Tracing distortion due to the finite stylus tip. Curves and formulas, of both frequency and amplitude distortion, as functions of recorded frequency, amplitude, linear speed, and tip radius.

B. Olney, Phonograph Pickup Tracking Error *vs* Distortion and Record Wear, *Electronics*, **10**, 19-23, 81 (November, 1937). Tracking error for straight and offset arms and its influence on distortion and record wear.

R. H. Ranger, Instantaneous Recording Needles, *Communications*, **17**, 16-17 (December, 1937). Needle characteristics and their influence on noise and distortion.

H. Bartels and **E. Severin**, On the Development of New Cutters and Pickups, *Telefunkenzeitung*, **75**, 27-37 (1937). Theoretical and practical considerations that enter into the design of new high quality recording and reproducing heads, and a description of their performance.

1938

L. Vieth and **C. F. Wiebusch**, Recent Development in Hill-and-Dale Recorder, *J. Soc. Motion Picture Engrs.*, **30**, 96-103 (January, 1938). A new recorder in which part of the output of the system is fed back to the input of the associated driving amplifier. Electrical feedback thus replaces the damping element usually provided in a vibrating system. The output of the feedback element is directly proportional to the stylus velocity.

D. G. Knapp, Offset Head Crystal Pickup, *Communications*, **18**, 28-29 (February, 1938). An exact formula is derived for optimum value of the ratio of overhang to pickup arm length (for nearly constant tracking error).

W. F. Wichart, A Turntable Wobble Indicator, *Electronics*, **11**, 13 (February, 1938). It is claimed that the instrument is fairly accurate and sensitive. Further advantages are its simplicity, portability, and low cost.

F. V. Hunt and **J. A. Pierce**, A Radical Departure in Pickup Design (HP6A), *Electronics*, **11**, 9-12 (March, 1938). Design of this reproducer is based on the principle of the velocity microphone. The pickup is characterized by its low needle impedance, low stylus pressure, and very wide (30 to 18,000 cps) and uniform frequency response. Methods to determine frequency characteristics of reproducers over such a wide range.

C. J. LeBel, Direct Disk Recording, *Electronics*, **11**, 22-25 (March, 1938). In producing high-fidelity instantaneous recordings, careful attention has to be paid to turntable, cutting head, record blank, and reproduction system.

A. W. Niemann, Measuring the Recording System with Limited Equipment, *Communications*, **18**, 14-15, 36-37 (May, 1938). Procedures for checking recording equipment with relatively simple measuring apparatus. Discussed are: impedance measurements, frequency characteristics, peak load capacity, nonlinear distortion, and maximum permissible recorded amplitude.

Two-Channel Pickup, *Communications*, **18**, 41 (June, 1938). A pickup with a gradually rising response at low frequencies, obtained with the aid of a special mechanical filter.

J. A. Pierce and **F. V. Hunt**, Distortion in Sound Reproduction from Phonograph Records, *J. Soc. Motion Picture Engrs.*, **31**, 157-186 (August, 1938). Analysis of the harmonic content of the curve traced by a spherical stylus tip when reproducing a sinusoidally modulated groove. The theory is developed for vertically and laterally cut grooves. It is shown that there are no even harmonics in the tracing distortion of lateral recordings. The results are displayed on a universal chart by contours of constant distortion.

G. J. Saliba, Automatic Equalization in Disk Recording, *Communications*, **18**, 15-16, 24 (August, 1938). New type of recording equalizer compensates continuously and automatically for the loss in high-frequency response during playback due to changing groove radius.

G. W. Downs and **W. Miller**, A d'Arsonval Reproducer for Lateral Recordings, *Communications*, **18**, 19-35 (October, 1938). In an original design a d'Arsonval type generator is developed with flat frequency response, light needle pressure, and true tracking. A permanent stylus is used.

C. J. LeBel, Advanced Disk Recording, *Electronics*, **11**, 34-36, 82 (November, 1938). How to extend the frequency range of a recording system, reduce its distortion, and control the signal-to-noise ratio, factors which make the difference between passable and excellent results.

J. G. Sperling, A Bibliography on Recording, *Communications*, **18**, 22, 27 (December, 1938).

P. Beerwald and **H. Keller**, Piezoelectric Crystal Elements for Electroacoustical Purposes, Part 1, *Funktech. Monatsh.*, **11**, 345-348 (1938).

E. Lindstrom, Recording Disks, *Ericsson Rev.*, 128-132 (1938). Records coated with cellulose lacquer giving good sound quality combined with freedom from noise.

E. G. Loefgren, On the Nonlinear Distortion in the Reproduction of Phonograph Records Caused by Angular Deviation of the Pickup Arm, *Akust. Z.*, **3**, 350-362 (1938). Theoretical investigation into pickup tracking. Sinusoidal and multitone groove modulation. It is shown that in the latter case the distortion represented by the combination tones may be quite considerable. Optimum off-set is determined for minimum distortion.

1939

H. J. Hasbrouck, Lateral Disk Recording for Immediate Playback with Extended Frequency and Volume Range, *Proc. I.R.E.*, **27**, 184-187 (March, 1939). New recording and reproducing equipment for broadcast use, including a cutting head operating on a power of approximately 1 watt and a new lightweight high-fidelity pickup.

E. T. Lynch, Some Considerations in Phonograph Pickup Design, *Brush Strokes*, **3**, 3 (April-June, 1939).

A. L. Williams, Further Improvements in Lightweight Record Reproducers, and Theoretical Considerations Entering into Their Design, *J. Soc. Motion Picture Engrs.*, **33**, 203-223 (August, 1939). Problems encountered in the design of pickups used for reproduction of high-quality acetate recordings. Formulas for optimum inertia, stiffness, and needle pressure, and suggestions to overcome interfering factors, such as uneven records and turntable surfaces.

A. Pinciroli, Electromagnetic Gramophone Pickups, *Alta Frequenza*, **8**, 637-657 (October, 1939).

N. B. Neely and **W. V. Stancil**, Modern Instantaneous Recording and Its Reproduction, *J. Soc. Motion Picture Engrs.*, **33**, 547-550 (November, 1939). Low-distortion recording head of balanced armature construction with a range from 50 to over 7000 cps and a lightweight high-quality pickup.

M. G. Scroggie, Gramophone Record Scratch, *Wireless World*, **46**, 3-7 (November, 1939). The frequency distribution of record scratch determined with the aid of a wave analyzer. Ways for reducing surface noise.

C. J. LeBel, Disk Cutting Problems, *Electronics*, **12**, 17-19 (December, 1939). Problems of high-frequency response, harmonic distortion, disk durability, and noise level in instantaneous recording. Practical advice on how to overcome some of the difficulties and

how to make performance checks on a number of units in a recording system.

R. Bierl, A Contribution to the Theory of Disk Recording—the Playback Process, *Akust. Z.*, **4**, 238-252 (1939). The theory is developed under the following assumptions: constant amplitude recording, ideally smooth groove, and spherical needle tip with infinite compliance. Maximum permissible amplitude and pinch effect magnitude are computed.

P. Beerwald and **H. Keller**, Piezoelectric Crystal Elements for Electroacoustical Purposes, Part 2, *Funktech. Monatsh.*, **11**, 97-100 (1939).

1940

S. L. Reiches, Volume Distortion, *J. Soc. Motion Picture Engrs.*, **34**, 59-75 (January, 1940). It is the author's thesis that, owing to the ear's sensitivity to frequencies as a function of loudness, a linear recording and reproducing system will not represent the original sound exactly. Correcting amplifier circuits with the desired characteristics are given.

H. F. Huon, The Cranked Pickup Arm. Mathematical Analysis of Tracking Error and Derivation of Optimum Design, *Proc. I.R.E. (Australia)*, **1**, 26-31 (February, 1940).

L. Vieth, Feedback Improves Electromechanical Recording, *Bell Labs. Record*, **18**, 171-173 (February, 1940). Description of 1A vertical recording system. Electrical signals are converted into corresponding vertical motions of the recording stylus which cuts the record.

A. W. Duffield, Improvements in Disk Records through Constant Amplitude Recording, *Communications*, **20**, 13-14, 28 (March, 1940). Problem of surface noise in the reproduction of shellac pressings, vinylite pressings, and acetate records. It is claimed that by recording "constant amplitude" at all frequencies a noise reduction is obtained owing to the inherent pre-emphasis.

A. J. Ebel, A Light Pattern Calibration Chart, *Communications*, **20**, 24-26 (April, 1940). Chart based on the optical pattern formula, showing the relationship between pattern width in centimeters and the recorded intensity in decibels. Zero decibel equals 1 cm.

K. de Boer, Experiments with Stereophonic Records, *Philips Tech. Rev.*, **5**, 182-186 (June, 1940). Two sound tracks and two pickups are used to provide the two channels needed for stereophonic reproduction.

G. J. Saliba, The Improved Automatic Equalizer for Disk Recording, *A.T.E. J.*, **7**, 18 (July, 1940). Improved radius compensating equalizer for recording at 33⅓ rpm.

Photoelectric Pickup, *Communications*, **20**, 13-14 (July, 1940). Description of a reproducer in which a small mirror moves with a jewel following the record groove. A beam of light is reflected by the mirror on a photoelectric cell, thus producing an electrical signal.

S. J. Begun, Some Problems of Disk Recording, *Proc. I.R.E.*, **28**, 389-398 (September, 1940). Lack of standardization in the recording field. Some general problems such as playback of shellac pressings, lateral *vs* vertical recording advantages, and cutting head design.

C. J. LeBel, Recent Improvements in Recording, *Electronics*, **13**, 33-35, 79-81 (September, 1940). New mechanical designs of turntables, improved cutters, playback heads, and equalizers show the trend toward higher fidelity in disk recording.

I. J. Abend, A High-Fidelity Recording Amplifier, *Electronics*, **13**, 44 (October, 1940). Simple recording amplifier with single-ended output and voltage feedback especially designed for driving recording heads.

H. A. Henning, Universal Phonograph Reproducer, *Bell Labs. Record*, **19**, 57-60 (October, 1940). The unit developed can be used on both vertical and lateral records. It consists of two voltage-generating coils mounted on a framework supported by two cantilever springs. The frequency response is essentially flat up to nearly 10,000 cps for both types of records.

J. C. Parvey, Some Notes on Vibratory Momentum and Groove Skating in Disk Recording, *Communications*, **20**, 22, 25-26 (October, 1940). A number of tests made with a relayed-flux type pickup and two moving coil type reproducers show the influence of vibratory momentum, needle impedance, and needle pressure on record wear and high-frequency response.

C. J. LeBel, Extended Experimental Study of the Optical Pattern, *Communications*, **20**, 22, 24 (December, 1940). A discussion is presented of the influence of hum, surface noise, and deviation from exactly lateral cut on an optical test pattern. Causes of unsymmetrical patterns and multitone test bands.

T. E. Lynch and **S. J. Begun**, General Considerations of the Crystal Cutter, *Communications*, **20**, 9-11, 26, 28, 29 (December, 1940). Rochelle salt crystal cutter, its operation and use in a recording system.

F. E. Williamson, Improving the Home Recorder, *Communications*, **20**, 15-16 (December, 1940). Improvements which can be made on a home recorder. The influence of the cutting stylus on the recording quality.

R. Bierl, The Error in the Light Band Width Measurement in Recording, *Akust. Z.*, **5**, 145-147 (1940). An exact theory of the light hand pattern effect on records, leading to the result derived by Buchmann and Meyer, modified by a correction factor.

M. Gruetzmacher and **W. Lottermoser**, The Recording of Small Variations in Pitch, *Akust. Z.*, **5**, 1-6 (1940). A measurement method which permits determination of pitch variations in the order of a fraction of 1%. Oscillograms showing fluctuations of constant frequency tones, reproduced from disks and film.

G. Guttwein, On Linear and Nonlinear Distortion in Recording and Playback, *Akust. Z.*, **5**, 330-349 (1940). Experimental investigation of the problems of frequency response ("linear" distortion) and amplitude or nonlinear distortion in lateral recording systems. Each link in the system is treated individually, and both lacquer disks and pressings are considered.

1941

L. Fleming, Notes on Phonograph Pickups for Lateral-Cut Records, *J. Acoust. Soc. Amer.*, **12**, 366-373 (January, 1941). Problems arising in pickup design, such as proper tracking, proportioning of mass and stiffness, and the importance of the pinch effect. The construction of a magnetic reproducer developed by the author.

C. J. LeBel, High-Frequency and Noise Level Characteristics of an Instantaneous Recording Disk, *A.T.E. J.*, **8**, 6 (January, 1941).

W. D. Lewis and **F. V. Hunt**, A Theory of Tracing Distortion in Sound Reproduction from Phonograph Records, *J. Acoust. Soc. Amer.*, **12**, 348-365 (January, 1941). General formulas for the motion of a stylus of any shape sliding on a groove modulated by an arbitrary recorded signal. Distortion for pure tones and many-tone signals and the effect of pre-emphasis on distortion.

G. E. MacDonald, Reduction of Pickup Tracking Error, *Communications*, **21**, 5-8, 22-24 (January, 1941). Definitions of tracking error and tracking angle and formulas for minimum tracking error conditions.

H. F. Olson, Tone Guard, *J. Acoust. Soc. Amer.*, **12**, 374-377 (January, 1941). Design of an acoustic network which, when used between door and cabinet, attenuates the sound radiated directly into the air by the vibrating parts of the pickup.

F. W. Stellwagen, Crystal Cutter and Channel for Lateral Recording, *Proc. Radio Club Amer.*, **18**, 29-44 (April, 1941).

D. R. King, A Ruler for Record Patterns, *Electronics*, **14**, 47 (May, 1941). This ruler converts the width of the "Christmas tree'" pat-

tern directly into decibels above or below a known reference.

S. J. Begun, Temperature-Controlled Disk Recording Cutter, *J. Soc. Motion Picture Engrs.*, **36**, 666-674 (June, 1941). Problems of temperature control and construction details of a crystal cutter. The influence of the cutter stiffness on its mechanical resonance and general performance.

W. A. Gunther, Recording Equipment Design, *Bull. assoc. suisse élec.*, **32**, 291-296 (July, 1941). Problems entering into the design of recording heads and pickups.

H. Rahmel, Variable Equalizer Amplifier, *Electronics*, **14**, 26-29, 61 (July, 1941). Amplifier with variable frequency characteristics permitting maximum fidelity reproduction of records made under a variety of recording conditions.

B. R. Carson, A Two-Side Non-Turnover Automatic Record Changer, *R.C.A. Rev.*, **6**, 183-189 (October, 1941). The use of two pickups, on each side of the record, eliminates the need for record turnover.

C. J. LeBel, Research Beats the Priorities, *Electronics*, **14**, 27-30, 78, 80, 82-83 (October, 1941). Replacement of aluminum by glass as a base material in disk recording and some of the new techniques in using this material.

W. J. Albersheim and **D. Mackenzie**, Analysis of Sound Film Drives, *J. Soc. Motion Picture Engrs.*, **37**, 452-454 (November, 1941). In order to avoid audible flutter the speed of sound reproducing systems must not vary more than 0.1%. Since such accuracy cannot be obtained with constant-speed motors and high-quality gears, mechanical filters must be used to suppress disturbances originating in motors, gears, and other drive elements.

H. G. Baerwald, Analytic Treatment of Tracking Error and Notes on Optimal Pickup Design, *J. Soc. Motion Picture Engrs.*, **37**, 591-622 (December, 1941). Analysis of tracking distortion for lateral-cut disks. The important fact is pointed out that the spectral character of this distortion stresses the higher frequency components. Pickup design, based on this analysis, is treated for straight arms, offset arms, and multipurpose arms. Simplified design equations are derived.

J. K. Hilliard, Distortion Tests by the Intermodulation Method, *Proc. I.R.E.*, **29**, 614-620 (December, 1941). A compact piece of test equipment which permits routine intermodulation measurements on sound recording and reproducing systems. Comparison between harmonic and intermodulation distortion test methods.

O. Kornei, On the Playback Loss in the Reproduction of Phonograph Records, *J. Soc. Motion Picture Engrs.*, **37**, 569-590 (December, 1941). A theory explaining the level losses occurring in playback of laterally cut records at higher audio frequencies. The performance of a spherical pickup stylus from the viewpoint of an elastic deformation of the record groove walls. Playback loss and translation loss related to pickup design.

O. Schaefer, The Equivalent Circuit of the Piezoelectric Pickup, *Akust. Z.*, **6**, 326-328 (1941). Since computation of the output voltage of a crystal pickup under load requires knowledge of the internal impedance, the latter is determined with the aid of an equivalent electric circuit.

1942

S. J. Begun and **T. E. Lynch**, The Correlation between Elastic Deformation and Vertical Forces in Lateral Recording, *J. Acoust. Soc. Amer.*, **13**, 284-287 (January, 1942). An investigation into the pinch effect, elastic properties of disk materials, and vertical compliance requirements in lateral reproducers.

F. H. Goldsmith, A Noise and Wear Reducing Phonograph Reproducer with Controlled Response, *J. Acoust. Soc. Amer.*, **13**, 281-283 (January, 1942). Design of a reproducer with replaceable needle giving low needle talk, acceptable quality, little record wear, and considerable reduction in record scratch.

C. J. LeBel, Properties of the Dulled Lacquer Cutting Stylus, *J. Acoust. Soc. Amer.*, **13**, 265-273 (January, 1942). Experimental study of the influence of burnishing standard lacquer cutting styli. Relations between recorded velocities, frequency, and recording diameter for different lengths of dulling.

J. D. Reid, A Large Radius Stylus for the Reproduction of Lateral-Cut Phonograph Records, *J. Acoust. Soc. Amer.*, **13**, 274-275 (January, 1942). Influence of the playback stylus tip radius on high-frequency response and signal-to-noise ratio is discussed and demonstrated by a number of measurements.

L. W. Sepmeyer, Tracing Distortion in the Reproduction of Constant-Amplitude Recordings, *J. Acoust. Soc. Amer.*, **13**, 276-280 (January, 1942). Analysis of playback distortion caused by the finite stylus tip in constant-amplitude and constant-velocity recording. Recommendations for optimum reproducer stylus radius and recorded amplitude.

J. B. Wiesner, The Recording Laboratory in the Library of Congress, *J. Acoust. Soc. Amer.*, **13**, 288-293 (January, 1942). Recording apparatus and techniques used by the Library of Congress record division.

A. Affelder, Preamplifier Filter for Crystal Pickup, *Electronics*, **15**, 78 (April, 1942). Preamplifier circuit for use in playing orthacoustic transcriptions, constant-velocity transcriptions, and ordinary phonograph records with a crystal pickup.

N. Hildebrand, Problems of Contrast Compression, *Funktech. Monatsh.*, **14**, 56-59 (April, 1942).

R. A. Lynne, A Discussion of Several Factors Contributing to a Good Recording, *R.C.A. Rev.*, **6**, 463-472 (April, 1942). The three main components which determine the over-all performance of a recording system are recording unit, disk, and reproducing apparatus.

O. Stephani, A Recording Head with Raised Natural Frequency for Foil Disks, *Funk (Berlin)*, 87-92 (April, 1942).

H. Fletcher, Hearing, the Determining Factor for High-Fidelity Transmission, *Proc. I.R.E.*, **30**, 266-277 (June, 1942). Requirements for ideal speech and music transmission systems based on extensive tests and measurements made under a variety of conditions. Comparison between a wide-band single-channel system and a narrow-band two-channel stereophonic system.

C. B. de Soto, How Recordings Are Made, *Q.S.T.*, **26**, Part 1: Principles of Disk Recording, 30-34, 94, 96 (July, 1942). Part 2: The Recorder, 56-59, 104, 110 (August, 1942). Part 3: The Amplifier, 65-72, 118, 120 (September, 1942). Part 4: Playback, 54-59, 114, 116, 118 (October, 1942). Part 5: Tests and Trouble Shooting, 51-55, 88, 90, 92, 106 (December, 1942). A detailed discussion of the practical aspects of disk recording.

H. Keller, Piezoelectric Pickup, *Hochfrequenztech. u. Elektroakustik*, **60**, 5-10 (July, 1942).

L. C. Smeby, Recording and Reproducing Standards, *Proc. I.R.E.*, **30**, 355-356 (August, 1942). Report on a series of standards adopted by the National Association of Broadcasters covering recording characteristics, dimensions of turntables, records and grooves, speeds, and label information.

M. Rettinger, A Modern Music Recording Studio, *J. Soc. Motion Picture Engrs.*, **39**, 186-194 (September, 1942). Description of a new recording studio and discussion of structural details, in particular the influence of convex wood splays on the reverberation characteristic.

P. L. Jensen, The Jensen Concert Needle, *Radio*, **26**, 24, 41 (October, 1942). A long-life playback needle with a precious metal tip has high compliance and low needle talk, and its use is claimed to result in a reduction of scratch and record wear.

H. D. Brailsford, Recording Machinery Noise, *Electronics*, **15**, 46-51, 164-166 (November, 1942). Cutting and playback apparatus used

for accurately recording sounds made by industrial and other equipment. Frequency spectrum analysis is then performed with oscilloscope, camera and sound analyzer.

1943

A. D. Burt, The Reduction of "Record Noise" by Pickup Design, *Electronics*, **16**, 90-93, 198, 199 (January, 1943). Crystal pickup in which the usually highly objectionable needle talk is removed at its source through special construction features of the reproducer. Test setup measured results.

H. E. Roys, The Measurement of Transcription-Turntable Speed Variation, *Proc. I.R.E.*, **31**, 52-55 (February, 1943). Review of some existing speed measurement equipment; need for simplified instrument to evaluate wow content as a single figure. Ballistic constants of indicating meter represent greatest design problem.

C. R. Keith, Sound Recording Depends upon Electronics, *Electronics*, **16**, 114-115 (March, 1943). General review of the recording field and its development since the 1920's.

G. L. Beers and **C. M. Sinnet**, Some Recent Developments in Record Reproducing Systems, *Proc. I.R.E.*, **31**, 138-146 (April, 1943). An experimental record reproducing system using the principle of frequency modulation; data on the measured and computed performance characteristics of the pickup.

A. J. Ebel, High-Fidelity Systems, *Communications*, **23**, 39-40, 42, 44 (April, 1943); 24, 26, 28, 62-63, 66-68, 70-71 (May, 1943). An ideal electroacoustic transmission system requires uniform frequency response from 20 to 15,000 cps, linear amplitude range of 75 db with 1% distortion, and a noise level 75 db below peak level.

T. R. Kennedy, Jr., Hi-Fi Transcribing, *Electronic Inds.*, **2**, 90-91, 161 (May, 1943). High-quality recordings are made off the air with special receiver and recording equipment perfected by the author.

Static Charges on Records, *Wireless World*, **49**, 165 (June, 1943). Glass base blanks are made with fiber insert to counteract the accumulation of an electrostatic charge.

A. M. Wiggins, Mechanical Impedance Bridge, *J. Acoust. Soc. Amer.*, **15**, 50-53 (July, 1943). Instrument to measure mechanical impedances of phonograph pickups over a frequency range from 30 to 10,000 cps.

1944

C. R. Miner, Wow Meter, *Gen. Elec. Rev.*, **47**, 31-34 (April, 1944). Simplified electronic instrument for measuring instantaneous variations of phonograph turntable speed. Based on the use of a 1000-cps frequency record, a frequency discriminator circuit, and an indicating meter.

R. Dally, Tone Arm Design, *Radio*, **28**, 34-36, 72 (July, 1944). Fundamental principles of tone arm design and practical considerations to be observed in their application.

R. Dally, Crystal Phonograph Pickups, *Radio*, **28**, 38-40, 46 (September, 1944). Operation, construction, and characteristics of crystal pickups and their application in reproducing systems.

W. C. Miller and **H. R. Kimball**, A Rerecording Console, Associated Circuits and Const. *B* Equalizer, *J. Soc. Motion Picture Engrs.*, **43**, 187-205 (September, 1944). Two-position rerecording console with sliding volume controls and preset equalization, also a variable-type attenuation equalizer circuit.

B. F. Miessner, Frequency-Modulation Phonograph Pickup, *Electronics*, **17**, 132-133 (November, 1944). Stylus movement causes a capacitance change in an oscillator circuit, thus producing frequency modulation. Pickup is claimed to have flat frequency characteristic, self-contained volume expansion, and operates with less than one ounce of needle pressure.

1945

Two-Speed Turntable for Transcription, *Electronics*, **18**, 230, 234 (January, 1945). Unit designed to prevent playing of 78-rpm disks erroneously at 33 1/3 rpm.

B. B. Bauer, Tracking Angle in Phonograph Pickups, *Electronics*, **18**, 110-115 (March, 1945). Offset arm design and an overhanging needle help minimizing tracking error of a phonograph pickup. Design equations for optimum conditions and a design chart for use with 12-inch records.

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A. Badmaieff, Push-Pull Frequency-Modulated Circuit and Its Application to Vibratory Systems, *J. Soc. Motion Picture Engrs.*, **46**, 37-51 (January, 1946). Push-pull action is accomplished by varying the resonant frequencies of both the oscillator and the discriminator in opposite phase relation to each other. Two capacitors with common plate achieve push-pull modulation. Applicable in the calibration of recording heads and the determination of their frequency response and distortion.

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Lateral Disk Recording, Part 2, *Broadcast Eng. J.*, **13**, 4-6, 9 (June, 1946). Discussion of sound energy distribution and equalization in disk recording. The use of the optical pattern in determining the frequency characteristic of a cutting head.

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Recent Advances in Wax Recording, *Bell System Tech. J.*, **8**, 159-172 (January, 1929). Frequency-response characteristics and limitations of lateral-cut wax records. Brief description of commercial processing methods.

Vertical Sound Records. Recent Fundamental Advances in Mechanical Records on Wax, *J. Soc. Motion Picture Engrs.*, **18**, 141-163 (February, 1932). It is claimed that vertical records possess certain advantages over lateral recordings. These advantages are discussed.

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Gilmore, J. P., see Ellis, A. B.

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The Reproduction of Disk Recordings, Part 2, *Radio-Electronic Eng.*, **8**, 3-6, 28 (January, 1947). Playback techniques, pickup stylus design, and equalization methods. Notes on magnetic pickup design and the use of a sweep frequency record in testing the performance of playback systems.

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Three-Band Variable Equalizer, *Electronics*, **20**, 112-115 (January, 1947). Flexible pre-equalizer provides gain or attenuation adjustment in 1-db steps independently in the low-, mid-, or high-frequency audio ranges.

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Guttwein, G., On Linear and Nonlinear Distortion in Recording and Playback, *Akust. Z.*, **5**, 330-349 (1940). Experimental investigation of the problems of frequency response ("linear" distortion) and amplitude or nonlinear distortion in lateral recording systems. Each link in the system is treated individually, and both lacquer disks and pressings are considered.

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Hall, C. I., The Induction Disk Phonograph Motor, *Gen. Elec. Rev.*, **24**, 218-221 (1921). Description of a new phonograph motor.

Hallman, L. B., Jr., Practical Volume Compression, *Electronics*, **9**, 15-17, 42 (June, 1936). New automatic volume compressor without cutoff on peaks and low distortion.

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See Frederick, H. A., Maxfield, J. P.

Hasbrouck, H. J., Lateral Disk Recording for Immediate Playback with Extended Frequency and Volume Range, *Proc. I.R.E.*, **27**, 184-187 (March, 1939). New recording and reproducing equipment for broadcast use, including a cutting head operating on a power of approximately 1 watt and a new lightweight high-fidelity pickup.

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Henning, H. A., Universal Phonograph Reproducer. *Bell Labs. Record,* **19,** 57-60 (October, 1940). The unit developed can be used on both vertical and lateral records. It consists of two voltage-generating coils mounted on a framework supported by two cantilever springs. The frequency response is essentially flat up to nearly 10,000 cps for both types of records.

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Hilliard, J. K., Distortion Tests by the Intermodulation Method, *Proc. I.R.E.,* **29,** 614-620 (December, 1941). A compact piece of test equipment which permits routine intermodulation measurements on sound recording and reproducing systems. Comparison between harmonic and intermodulation distortion test methods.

Intermodulation Testing, *Electronics,* **19,** 123-127 (July, 1946). Fidelity of audio amplifiers is determined by intermodulation tests. Results thus obtained show closer correlation with actual listener tests than harmonic distortion measurements.

Intermodulation Tests for Comparison of Beam and Tetrode Tubes Used to Drive Loudspeakers, *Communications,* **26,** 15-17, 54 (February, 1946). Examination of the outputs of 10-, 15-, 40-, and 50-watt amplifiers with beam power and triode tubes using an intermodulation analyzer. Comparison of results with actual listening tests.

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Hunt, F. V., see Lewis, W. D.

——— and Pierce, J. A., A Radical Departure in Pickup Design (HP6A), *Electronics,* **11,** 9-12 (March, 1938). Design of this reproducer is based on the principle of the velocity microphone. The pickup is characterized by its low needle impedance, low stylus pressure, and very wide (30 to 18,000 cps) and uniform frequency response. Methods to determine frequency characteristics of reproducers over such a wide range.

See Pierce, J. A.

Huon, H. F., The Cranked Pickup Arm. Mathematical Analysis of Tracking Error and Derivation of Optimum Design, *Proc. I.R.E. (Australia),* **1,** 26-31 (February, 1940).

Irany, E. P., New Synthetic Resins in Manufacture of Gramophone Records, *Can. Chem. Met.,* **20,** 193-195 (June, 1936). Requirements for gramophone records and some of the new resins used.

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John, R. S., see Germeshausen, K. J.

Just, P., see Meyer, E.

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Kalmus, H. P., Pickup with Low Mechanical Impedance, *Electronics,* **19,** 140-145 (January, 1946). Amplitude modulation is produced in a radio-frequency oscillator owing to variation in its losses, which is caused by the movement of a metallic vane attached to the stylus. Pickup has low mechanical impedance.

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Kaufman, E. N., see Kaufman, A. B.

Kaufmann, K., Saja, Single-Phase Synchronous Motor for Recorders, *Elektrotech. Z.,* **55,** 213-214 (March, 1934). Data for a heavy-duty type motor, with hand starting and a speed of 78 rpm at 50 cps line frequency.

Kees, A. A., Recording and Broadcasting of Preparation for Bikini Atom-Bomb Test, *Communications,* **26,** 11-13 (July, 1946). Methods used to prepare "on spot" recordings in planes, at sea, and on land. Amplifiers and recording equipment are selected to operate under conditions of extreme temperature and vibrations.

Keith, C. R., Sound Recording Depends upon Electronics, *Electronics,* **16,** 114-115 (March, 1943). General review of the recording field and its development since the 1920's.

Keller, A. C., Direct Recording and Reproducing Materials for Disk Recordings, *J. Soc. Motion Picture Engrs.,* **28,** 411-426 (April, 1937). Materials available for direct disk recording classified chemically in five groups, and measurements of frequency characteristics, surface noise, life, and distortion. Data for both lateral and vertical recording.

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See Beerwald, P.

Kellogg, E. W., Electrical Reproduction from Phonograph Records, *J. Am. Inst. Elec. Engrs.,* **46,** 903-912 (October, 1927). First of the three steps in phonograph reproduction: generation of voltage by needle vibrations. Electrostatic, piezoelectric, electromagnetic, and variable resistance pickups discussed.

A Review of the Quest for Constant Speed, *J. Soc. Motion Picture Engrs.,* **28,** 337-376 (April, 1937). Importance of constant record speed. Brief descriptions and discussions of a number of ingenious arrangements for improving speed constancy, some applicable to turntables, some to film drives.

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Kennedy, T. R., Jr., Hi-Fi Transcribing, *Electronic Inds.,* **2,** 90-91, 161 (May, 1943). High-quality recordings are made off the air with special receiver and recording equipment perfected by the author.

Kimball, H. R., see Miller, W. C.

King, D. R., A Ruler for Record Patterns, *Electronics,* **14,** 47 (May, 1941). This ruler converts the width of the "Christmas tree" pattern directly into decibels above or below a known reference.

Kluge, M., Frequency Response and Record Wear of Pickups, *Hochfrequenztech. u. Elektroakustik,* **40,** 55-65, 108-111 (August, September, 1932). Theoretical and experimental study of electromagnetic pickups and mechanical phonographs.

Knapp, D. G., Offset Head Crystal Pickup, *Communications,* **18,** 28-29 (February, 1938). An exact formula is derived for optimum value of the ratio of overhang to pickup arm length (for nearly constant tracking error).

Kornei, O., On the Playback Loss in the Reproduction of Phonograph Records, *J. Soc. Motion Picture Engrs.*, **37**, 569-590 (December, 1941). A theory explaining the level losses occurring in playback of laterally cut records at higher audio frequencies. The performance of a spherical pickup stylus from the viewpoint of an elastic deformation of the record groove walls. Playback loss and translation loss related to pickup design.

LeBel, C. J., Advanced Disk Recording, *Electronics*, **11**, 34-36, 82 (November, 1938). How to extend the frequency range of a recording system, reduce its distortion, and control the signal-to-noise ratio, factors which make the difference between passable and excellent results.

Direct Disk Recording, *Electronics*, **11**, 22-25 (March, 1938). In producing high-fidelity instantaneous recordings, careful attention has to be paid to turntable, cutting head, record blank, and reproduction system.

Disk Cutting Problems, *Electronics*, **12**, 17-19 (December, 1939). Problems of high-frequency response, harmonic distortion, disk durability, and noise level in instantaneous recording. Practical advice on how to overcome some of the difficulties and how to make performance checks on a number of units in a recording system.

Extended Experimental Study of the Optical Pattern, *Communications*, **20**, 22, 24 (December, 1940). A discussion is presented of the influence of hum, surface noise, and deviation from exactly lateral cut on an optical test pattern. Causes of unsymmetrical patterns and multitone test bands.

High-Frequency and Noise Level Characteristics of an Instantaneous Recording Disk, *A.T.E. J.*, **8**, 6 (January, 1941).

Properties of the Dulled Lacquer Cutting Stylus, *J. Acoust. Soc. Amer.*, **13**, 265-273 (January, 1942). Experimental study of the influence of burnishing standard lacquer cutting styli. Relations between recorded velocities, frequency and recording diameter for different lengths of dulling.

Quality in Disk Reproduction, *Electronics*, **10**, 25-27, 77 (October, 1937). Turntables and pickups and suggestions for improvement in reproducing systems given.

Recent Improvements in Recording, *Electronics*, **13**, 33-35, 79-81 (September, 1940). New mechanical designs of turntables, improved cutters, playback heads, and equalizers show the trend toward higher fidelity in disk recording.

Research Beats the Priorities, *Electronics*, **14**, 27-30, 78, 80, 82-83 (October, 1941). Replacement of aluminum by glass as a base material in disk recording and some of the new techniques in using this material.

Ledbetter, J. B., Placement and Operation of Microphones in Broadcast Studios, *Communications*, **26**, 12, 13, 15 (December, 1946). Analysis of microphone arrangements and discussion of phasing of microphones.

Leidel, W. F., Jr., and Payne, N. E., Tuned-Ribbon Pickup, *Electronic Inds.*, **5**, 67-69, 100-101 (October, 1946). New reproducer extends playback range to 15 kc, providing at the same time "magnetic cushion" for record noise suppression. Discussion of the various forces acting on a pickup during playback.

Leitner, R. G., New Vibrating Reed Magnetic Pickup, *Radio*, **29**, 25, 63 (December, 1945). Design, construction, and operating characteristics of a new type of magnetic pickup. Frequency-response curves with and without damping.

Lewis, W. D., and Hunt, F. V., A Theory of Tracing Distortion in Sound Reproduction from Phonograph Records, *J. Acoust. Soc. Amer.*, **12**, 348-365 (January, 1941). General formulas for the motion of a stylus of any shape sliding on a groove modulated by an arbitrary recorded signal. Distortion for pure tones and many-tone signals and the effect of pre-emphasis on distortion.

Lindenberg, Th., Jr., Moving-Coil Pickup Design, *Electronics*, **18**, 108-110 (June, 1945); Correspondence, *Electronics*, **18**, 416, 424 (September, 1945). Reproducer with its mechanical resonance practically at the limit of audibility, thus ensuring light needle pressure and negligible record wear.

Lindstrom, E., Recording Disks, *Ericsson Rev.*, 128-132 (1938). Records coated with cellulose lacquer giving good sound quality combined with freedom from noise.

Loefgren, E. G., On the Nonlinear Distortion in the Reproduction of Phonograph Records Caused by Angular Deviation of the Pickup Arm, *Akust. Z.*, **3**, 350-362 (1938). Theoretical investigation into pickup tracking. Sinusoidal and multitone groove modulation. It is shown that in the latter case the distortion represented by the combination tones may be quite considerable. Optimum off-set is determined for minimum distortion.

Lottermoser, W., see Gruetzmacher, M.

Lynch, E. T., Some Considerations in Phonograph Pickup Design, *Brush Strokes*, **3**, 3 (April-June, 1939).

Lynch, T. E., and Begun, S. J., General Considerations of the Crystal Cutter, *Communications*, **20**, 9-11, 26, 28, 29 (December, 1940). Rochelle salt crystal cutter, its operation and use in a recording system.

See Begun, S. J.

Lynne, R. A., A Discussion of Several Factors Contributing to a Good Recording, *R.C.A. Rev.*, **6**, 463-472 (April, 1942). The three main components which determine the over-all performance of a recording system are recording unit, disk, and reproducing apparatus.

MacDonald, G. E., Reduction of Pickup Tracking Error, *Communications*, **21**, 5-8, 22-24 (January, 1941). Definitions of tracking error and tracking angle and formulas for minimum tracking error conditions.

Mackenzie, D., see Albersheim, W. J.

MacNair, W. A., see Shea, T. E.

Massa, F., Permissible Amplitude Distortion of Speech in an Audio Reproducing System, *Proc. I.R.E.*, **21**, 682-689 (May, 1933). Experimental investigation of the effect of distortion on the character of audio reproduction in wide and narrow frequency channel systems.

Maxfield, J. P., and Harrison, H. C., Methods of High-Quality Recording of Music and Speech Based on Telephone Research, *J. Am. Inst. Elec. Engrs.*, **45**, 334-348 (February, 1926). Analysis of requirements for recording and reproducing sound. Complete description of application of electrical transmission theory to mechanical vibratory systems is most important feature of paper.

Maxwell, D. E., Automatic Gain Adjusting Amplifier, *Tele-Tech*, **6**, 34-36, 128 (February, 1947). Information on design and engineering of the CBS 1-A peak-limiting amplifier, characterized by short attack time to prevent splatter, low compression level, and elimination of pumping.

Meyer, E., see Buchmann, G.

——— and Just, P., Frequency Curves of Electric Pickups and Mechanical Gramophones, *Elek. Nachr.-Tech.*, **6**, 264-268 (July, 1929). Characteristic frequency curves for a number of pickups and the calibration of a test record.

Miessner, B. F., Frequency-Modulation Phonograph Pickup, *Electronics*, **17**, 132-133 (November, 1944). Stylus movement causes a capacitance change in an oscillator circuit, thus producing frequency modulation. Pickup is claimed to have flat frequency characteristic, self-contained volume expansion, and operates with less than one ounce of needle pressure.

Michel, B. M. H., see Goodell, J. D.

Miller, G. H., Improving Broadcast of Recorded Programs, *Electronics*, **7**, 178 (June, 1934). By using a wave filter and resistance pad during playback, giving a characteristic complementary to that used in recording, an over-all system with improved low-frequency response is obtained.

Miller, W., see Downs, G. W.

Miller, W. C., and Kimball, H. R., A Rerecording Console, Associated Circuits, and Const. *B* Equalizer, *J. Soc. Motion Picture Engrs.*, **43**, 187-205 (September, 1944). Two-position rerecording console with sliding volume controls and preset equalization, also a variable-type attenuation equalizer circuit.

Miner, C. R., Wow Meter, *Gen. Elec. Rev.*, **47**, 31-34 (April, 1944). Simplified electronic instrument for measuring instantaneous variations of phonograph turntable speed. Based on the use of a 1000-cps frequency record, a frequency discriminator circuit, and an indicating meter.

Misener, G. C., Optical Cueing Device for Disk Playback, *J. Soc. Motion Picture Engrs.*, **45**, 297-301 (October, 1945). Simple optical arrangement which permits accurate placement of pickup stylus on the disk for cueing purposes.

Morgan, A. R., see Kellogg, E. W.

Morgan, K. F., and Shea, T. E., The Electrical Engineering of Sound Picture Systems, *J. Am. Inst. Elec. Engrs.*, **48**, 766-770 (October, 1929). Methods and apparatus for sound recording and reproducing with emphasis on electrical engineering aspects.

Neely, N. B., and Stancil, W. V., Modern Instantaneous Recording and Its Reproduction, *J. Soc. Motion Picture Engrs.*, **33**, 547-550 (November, 1939). Low-distortion recording head of balanced armature construction with a range from 50 to over 7000 cps and a lightweight high-quality pickup.

Niemann, A. W., Measuring the Recording System with Limited Equipment, *Communications*, **18**, 14-15, 36-37 (May, 1938). Procedures for checking recording equipment with relatively simple measuring apparatus. Discussed are: impedance measurements, frequency characteristics, peak load capacity, nonlinear distortion, and maximum permissible recorded amplitude.

Nixon, G. M., and Volkmann, J., Design of Recording Studios for Speech and Music, *Tele-Tech*, **6**, 37-39 (February, 1947). Data on the adjustment of reverberation time *vs* frequency characteristics to fit requirements for broadcast transcriptions and home records.

Norden, K., Electric Phonograph, *Elektrotech. Z.*, **48**, 261-264 (March, 1927). Description of electric pickup, ac-operated amplifier used in German equipment based on American licenses.

Ollard, E. A., Gramophone Record Matrices, *Metal Ind. (London)*, **49**, 165-169 (August, 1936); 239-242, 265-266 (September, 1936). Electroplating process used in manufacturing matrices.

Olney, B., Phonograph Pickup Tracking Error *vs* Distortion and Record Wear, *Electronics*, **10**, 19-23, 81 (November, 1937). Tracking error for straight and offset arms and its influence on distortion and record wear.

Olson, H. F., Tone Guard, *J. Acoust. Soc. Amer.*, **12**, 374-377 (January, 1941). Design of an acoustic network which, when used between door and cabinet, attenuates the sound radiated directly into the air by the vibrating parts of the pickup.

Parvey, J. C., Some Notes on Vibratory Momentum and Groove Skating in Disk Recording, *Communications*, **20**, 22, 25-26 (October, 1940). A number of tests made with a relayed-flux type pickup and two moving coil type reproducers show the influence of vibratory momentum, needle impedance, and needle pressure on record wear and high-frequency response.

Payne, N. E., see Leidel, W. F., Jr.

Pfannenstiehl, H., A Reproducing Machine for Picture and Sound, *Bell Labs. Record*, **8**, 28-31 (September, 1929).

Pickering, N. C., Improving Recordings, *Electronic Inds.*, **4**, 82-84, 206, 210, 214 (October, 1945). How to get the most out of phonograph records through proper adjustment of frequency range, reduction of distortion, and the use of a new type of volume expander which increases "presence."

Measuring Audio Intermodulation, *Electronic Inds.*, **5**, 56-58, 124-125 (June, 1946). Methods and equipment for analyzing audio distortion by the application of two signals to the tested device. Relationship between harmonic and intermodulation distortion.

Pierce, J. A., and Hunt, F. V., Distortion in Sound Reproduction from Phonograph Records, *J. Soc. Motion Picture Engrs.*, **31**, 157-186 (August, 1938). Analysis of the harmonic content of the curve traced by a spherical stylus tip when reproducing a sinusoidally modulated groove. The theory is developed for vertically and laterally cut grooves. It is shown that there are no even harmonics in the tracing distortion of lateral recordings. The results are displayed on a universal chart by contours of constant distortion.

See Hunt, F. V.

Pinciroli, A., Electromagnetic Gramophone Pickups, *Alta Frequenza*, **8**, 637-657 (October, 1939).

Podliasky, J., Distortion in Recording and Reproducing Sound, *L'Onde élec.*, **11**, 380-394 (1932). Fundamentals of recording and causes of distortion analyzed.

Rahmel, H., Variable Equalizer Amplifier, *Electronics*, **14**, 26-29, 61 (July, 1941). Amplifier with variable frequency characteristics permitting maximum fidelity reproduction of records made under a variety of recording conditions

Ranger, R. H., Instantaneous Recording Needles, *Communications*, **17**, 16-17 (December, 1937). Needle characteristics and their influence on noise and distortion.

Record, F., Gramophone Tracking, *J. Sci. Instr.*, **9**, 286-289 (September, 1932). Geometrical investigation into the problem of tracking.

Reiches, S. L., Volume Distortion, *J. Soc. Motion Picture Engrs.*, **34**, 59-75 (January, 1940). It is the author's thesis that, owing to the ear's sensitivity to frequencies as a function of loudness, a linear recording and reproducing system will not represent the original sound exactly. Correcting amplifier circuits with the desired characteristics are given.

Reid, J. D., A Large Radius Stylus for the Reproduction of Lateral-Cut Phonograph Records, *J. Acoust. Soc. Amer.*, **13**, 274-275 (January, 1942). Influence of the playback stylus tip radius on high-frequency response and signal-to-noise ratio is discussed and demonstrated by a number of measurements.

Rettinger, M., A Modern Music Recording Studio, *J. Soc. Motion Picture Engrs.*, **39**, 186-194 (September, 1942). Description of a new recording studio and discussion of structural details, in particular the influence of convex wood splays on the reverberation characteristic.

Rich, S. T., Torsional Magnetostriction Pickup, *Electronics*, **19**, 107-109 (June, 1946). Design and characteristics of a phonograph pickup operating on leakage flux in a torsional magnetostriction system. Wide frequency response and ruggedness are obtained with a small moving mass and low distortion.

Robinson, W. H., Lateral Recording, *Communications*, **27**, 26, 28 (February, 1947). Electromagnetic and crystal cutters, groove depths, disks, volume indicators, measuring setups, frequency runs, styli, cutting angles, scratch filters, and pickups.

Roys, H. E., Experience with an FM Calibrator for Disk Recording Heads, *J. Soc. Motion Picture Engrs.*, **44**, 461-471 (June, 1945).

Performance of cutting heads under different load conditions, i.e., in air, cutting at 78 rpm, and 33⅓ rpm. Variations in recorded level with groove width and cutting stylus.

The Measurement of Transcription-Turntable Speed Variation, *Proc. I.R.E.*, **31**, 52-55 (February, 1943). Review of some existing speed measurement equipment; need for simplified instrument to evaluate wow content as a single figure. Ballistic constants of indicating meter represent greatest design problem.

Recently Developed Tools for the Study of Disk Recording Performance, presented at A.I.E.E. winter convention, New York, January, 1946; see also *Communications*, **26**, 33, 35 (April, 1946). Investigation and measurements of cutting force, cutting head bounce, lacquer hardness variation, turntable speed accuracy, and intermodulation distortion.

Saliba, G. J., Automatic Equalization in Disk Recording, *Communications*, **18**, 15-16, 24 (August, 1938). New type of recording equalizer compensates continuously and automatically for the loss in high-frequency response during playback due to changing groove radius.

High-Fidelity Instantaneous Recording, *Communications*, **16**, 11-13 (January, 1936). Recording techniques using disks with cellulose coatings. High-frequency response depends on relation between radius or curvature of modulated groove and playback stylus tip. Details of cutting-head feed arrangement and a complete portable recorder.

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Two-Speed Turntable for Transcription, *Electronics*, **18**, 230, 234 (January, 1945). Unit designed to prevent playing of 78-rpm disks erroneously at 33⅓ rpm.

Fabian Bachrach

Edwin Howard Armstrong 1890-1954

On February 1 of this year, Major Edwin H. Armstrong passed away at his home in New York City. His passing marks the close of one of the most brilliant and colorful careers in the communications field. During his student days he was influenced by the ideas of the early experimenters in electricity and radio from Watt to Marconi. While at Columbia he studied under the physicist Michael Pupin. Some years later Armstrong was to be appointed to the academic position held by Pupin, Head of the Marcellus Hartly Research Laboratory, after serving as assistant to the physicist.

Armstrong was one of the early wireless pioneers in the United States, starting with an amateur radio station in 1905.

Armstrong was a great teacher as well as an inventor, and his lectures and public talks were notable for his care of presentation and patience in explaining the finer points of his presentation.

Armstrong developed the tuned regenerative circuit which provided the basis for the regenerative receiver and a wide variety of oscillators. This was done while he was still in college. Later he developed the superheterodyne circuit which is the basis of almost all modern radio receiving and radar equipment. Another of his ideas, the super-regenerative detector, opened the door to high-gain receivers for the frequencies above 30 megacycles. This circuit provides tremendous gain in a single tube circuit, and for many years it formed the heart of the police radio systems.

All of his earlier contributions were swiftly overshadowed by his disclosure and development of the principles of frequency modulation in the mid-1930's. Although the communications facility and fidelity of reproduction of FM were clearly demonstrated by Armstrong in broadcasts from a station he erected with his own money, commercial acceptance of FM was not great. The reasons are many, and even today because of restriction of FM stations to "single market" areas and limitation of station power, FM is not expanding rapidly. The fact that it enables the transmission of wide-range audio signals and provides static-free reception has not been able to overcome the commercial and regulatory hindrances to its growth.

Last fall Armstrong presented the results of his work in the field of multiplexing wide-range audio signals over an existing single-channel FM broadcasting station, in a paper presented before a joint meeting of the Audio Engineering Society and the Radio Club of America.

During both world wars Armstrong served his country in the field of communications. His FM system made possible reliable mobile radio equipment for our infantry and artillery forces throughout the world. Without FM, mobile force communications would have been hampered by a variety of problems.

Major Armstrong was an honorary member of the Institute of Radio Engineers, Australia, The Franklin Institute, and the American Institute of Electrical Engineers, and a noted member of the Radio Club of America.

He was the holder of three degrees of Doctor of Science and the recipient of more than a dozen awards for outstanding achievement.

He is survived by his wife, Marian MacInnis Armstrong.

It is with the greatest regret that we here must record the passing of Major Armstrong, a man whose dedicated example and brilliant work will remain as a living tribute.

Book Review

Fields and Waves in Modern Radio

SIMON RAMO AND JOHN R. WHINNERY, John Wiley & Sons, Inc., 440 Fourth Avenue, New York 16, N. Y., 576 pages, $8.75.

This is a second edition of a book originally published in 1944, which found a considerable readership among engineers, advanced students, and instructors especially concerned with the theory of electromagnetic waves and oscillations. The present edition contains slightly more than 10% more material than the first edition and has been considerably revised, bringing it as nearly up to date as the inevitable time lag in book editing and production permits.

The treatment is at a fairly advanced level, in textbook style, with copious use of illustrative examples, and suitable problems at the end of each section. The material is presented in a logical order for classroom instruction, beginning with fundamentals of EM waves and oscillations. After development of the necessary concepts, with particular attention to the equation for simple harmonic motion and its solution, the equations for static electric and magnetic fields are treated. Maxwell's equations are then taken up, followed by circuit concepts as derived from the field equations.

Propagation and reflection of EM waves are covered next, followed by treatment of guided waves, and physical systems for guiding them, such as transmission lines and wave guides. Resonant cavities and microwave networks are covered in two chapters, followed by a final chapter on radiation and antennas.

The treatment throughout is solidly mathematical without being exhaustive, but with enough consideration of physical concepts to provide an adequate physical picture of the phenomena involved. As compared to the previous edition, this one uses the mks system of units throughout and contains a considerable amount of new material, as well as additional problems for study and review purposes. The early introduction of the Smith chart is noteworthy, as are several new aspects of wave propagation, such as slow-wave circuits and the principle of duality. There are also several new features in the chapter on radiation, including a discussion of horns and slot antennas.

In general, the text seems uncommonly free from serious omissions or redundancies, perhaps as the result of the authors' years of familiarity through its use in teaching senior and first-year graduate courses in the subject. Its value to persons interested solely in the world of mechanical vibrations is minimal, but to the engineer who must concern himself with such additional fields as television broadcasting, microwave relays, and radar, the book can be of real value. Its usefulness as a teaching text in EM wave theory has already been demonstrated in the authors' own pedagogical work.

L. JEROME STANTON
151 Eighth Avenue
New York 11, N. Y.

Letters

Disk Standard Comment

I note with interest in the last issue of the *Journal* the proposal to change the AES Disk Standard to what is apparently the same as the NARTB and the Victor New Orthophonic.

While the latest recording curves of all of the major companies have become so closely alike that some sort of standardization seems desirable and inevitable, I am sending the following comments for what they may be worth. They are based upon our experience in devising equipment and equalizers to play a wide variety of recording characteristics.

It has been my observation that among present commercial recordings the most obvious and consistent defect is a roughness in the high-frequency reproduction, which I have attributed (either rightly or wrongly) to the large amount of pre-emphasis being used. On this basis, it appears to me that the increase in pre-emphasis of the new NARTB curve over the old AES curve is a *disadvantage*.

On the other hand, the problems with rumble, record eccentricity, etc., are exaggerated by the absence of "bass pre-emphasis" in the old AES curve, and for this reason, therefore, adoption of the NARTB curve is probably an improvement so far as the low-frequency characteristic is concerned. While this newer curve might quite conceivably cause more low-frequency distortion, it would appear that if this occurs it is not generally particularly noticeable, and the use of variable pitch recording and other modern techniques can accommodate this type of bass characteristic. While we manufacture a device that copes quite effectively with the rumble problem, I nevertheless believe that the inherent rumble reduction resulting from the suggested change in characteristic is well worth while.

I realize that the actual differences between the old and the proposed new AES curves are actually small and less than other variations which exist in the recording and reproducing systems. It does appear to me, however, that the change in the low-frequency characteristic is in the direction for good, while the change in the high-frequency characteristic is possibly in the wrong direction.

H. H. Scott
385 Putnam Ave.
Cambridge 39, Mass.
February 22, 1954

Amplifier Test Procedure

The section in Vol. 2, No. 1, on p. 56 attracted my attention. The feature I should like to mention is associated with the method of measurement, but in a way that often escapes attention.

Whatever standards are set for an amplifier performance, they are normally measured with the amplifier working into a resistance load. Unfortunately our ears are rather insensitive to audio energy dissipated as heat in a pure resistance, so we have to feed the energy into a loudspeaker for practical purposes. Under this condition the behavior of an amplifier may be very different from its behavior as measured into a resistance load; this is especially true of modern feedback amplifiers.

I realize that any endeavor to present facts of value in assessing performance into a loudspeaker load would complicate the establishing of standards, but it seems to be important, because without some reference of this type the standards are virtually meaningless when applied to practical operating conditions.

Norman H. Crowhurst
150-46 18th Avenue
Whitestone 57, N. Y.
February 23, 1954

More on High Fidelity

Any day of the week will bring forth numerous claims of "high-fidelity," "response from 50 to 15,000 cps," "distortionless reproduction," etc. Other claims are made for "stereophonic sound," "full dimensional sound," "3-D sound," and almost anything else the copywriter can think of. These pipedreams are not the exclusive property of Johnny-come-latelys to the field, either. Some firms which should know better are guilty, too.

The public is properly confused, and who can blame them. On one hand they hear that "high-fidelity" is a rather elusive thing, to be had only by the careful selection of the highest quality components through the outlay of several hundred dollars. On the other hand, advertisements of certain reputable manufacturers tell them that a tabletop phonograph priced in the neighborhood of $100 will give musical reproduction better than the original source.

The situation in the field of quality components is better, but still confusing. Speakers are offered with all sorts of claims. Amplifiers and other components are advertised with various specifications, none of which are reached by the same method.

The same holds true for tape recorders. It is possible for the consumer to purchase a recorder, flat ±2 db from 50 to 15,000 cps, with a price tag of $300 to $1000. Or, he can go to the local jewelry or music store and for a mere $129.50 purchase a recorder with a response of 30 to 15,000 cps. To say the least, the public is apt to be confused—and to say the most, it will be badly misled.

Something should be done about this labeling of every piece of machinery capable of audible sound "high-fidelity." A possible solution lies with the Standards Committee. It might well be that they are working on the problem at the present time. If they are not, the following course of action might be followed.

1. The AES to set standards for measuring IM, harmonic, and frequency distortion; also rated output of amplifiers. Similar standards could be put forth for other components. Many methods of checking equipment are available. The acceptance of any one of them would at least tie things down to a standard. The public would then have a basis for comparison. Manufacturers could then advertise their products with AES specifications.

2. The AES to approve laboratories to certify that certain products fall within the high-fidelity category. Actually, the AES wouldn't have to define "hi-fi." For example, if the XYZ Tape Recorder is put before the public with specifications of ±2 db from 50 to 8000 cps, and these specifications are correct according to AES standards, then this product could be given approval. On the other hand, the RST Record Player, measuring over-all 18" × 18" × 14" and claiming high-fidelity, 30 to 15,000 cps, etc., would not receive this approval.

3. A slight fee to be charged by the laboratories for the work done on products being tested for approval.

The above plan is somewhat sketchy and leaves many problems unsolved, but audio is becoming a somewhat overloaded bandwagon. Something should be done to keep the control of high-fidelity out of the hands of shopkeepers and advertising agencies.

Fritz Held
3117 Atwater Avenue,
Los Angeles 39, Calif.
November 29, 1953

AES News

Notice to Members

The Secretary of the Society should be advised immediately of any change of address by a member or subscriber to the *Journal*. If new address information is not filed with the Secretary, *Journal* copies will be lost. Please include your old address along with the new one when notifying the Secretary. If convenient include the stencil impression from a *Journal* envelope or other AES mailing. This will expedite preparation of a new stencil.

Journal Adds New Editors

The appointment of George E. Gynn of Magnecord, Inc., and Julius Postal of Tele-Science Productions as Associate Editors has been announced by the Editor. These additions to the staff will permit faster *Journal* production and enable closer cooperation between the *Journal* and the numerous sections of the Society throughout the country. Among the changes effected by the larger staff is the division of the fields of audio engineering among the editors so that each editor will handle only those papers in certain categories. The fields of activity of each editor are as follows:

Lewis S. Goodfriend, 404 Riverside Drive, New York 25, New York.
Tape and disk recording, speech and hearing, architectural acoustics, book reviews, news, letters to the Editor.

George E. Gynn, c/o Magnecord, Inc., 225 W. Ohio Street, Chicago 10, Illinois.
Amplifiers, broadcasting systems, modulation and demodulation systems, components, telemetering, and circuits.

Julius Postal. 8 State Street, New York 4, New York.
Audio-visual aids, optical and magnetic film recording, stereophonic systems, information theory, standards, nomenclature, activities of other professional societies.

Vincent Salmon, 765 Hobart Street, Menlo Park, California
Transducers, physical acoustics, dynamical systems, acoustical filters, propagation acoustics, acoustical measurements, instrumentation, musical acoustics.

Authors are requested to submit manuscripts in the various fields directly to the appropriate editor at the address shown. News concerning members' activities will be published in the *Journal* whenever sufficient details are sent to the Editor. When possible these news items should be accompanied by a 5 × 7-inch glossy photograph. The News column will also feature reports on the activities of other professional societies which may be of interest to AES members.

It is hoped that the members of the AES will take full advantage of the expanded *Journal* staff and continue to submit papers of interest in all branches of audio.

New Audio Fair Contract Signed

Jerry B. Minter, AES President, has announced the signing of a new contract by the Society and Harry N. Reizes, Fair Manager. This contract continues the Society's sponsorship of the Audio Fair and sets up a new exhibit feature. This feature is the provision of a new professional exhibit area, under the control of the AES, to which members will be admitted without charge. Nonmembers of the AES will pay an entrance fee which will also entitle them to attend the technical sessions. A registration fee for admission to the technical sessions will also be charged for nonmembers who do not attend the professional exhibits.

In the professional exhibit area there will be no audible demonstrations. Thus engineers will be able to discuss design problems with exhibitors without a high level background.

Since contract forms for space for the 1954 Audio Fair will be sent out shortly, anyone desiring to take advantage of the new professional exhibit facilities should communicate with Harry N. Reizes, 67 West 44th Street, New York 36, New York (MUrray Hill 7-2080).

Harry N. Reizes signs new contract as Audio Fair manager while C. R. Sawyer, Jerry B. Minter, and Walter A. Stanton look on.

Errata

J. D. Bick, "Methods of Measuring Surface Induction of Magnetic Tape," Vol. 1, No. 1, p. 4.

The following confusion of terminology with respect to this paper has been brought to light. Surface induction as defined by NARTB is "the flux density (B) at right angles to the surface of the tape." A recording having constant flux *vs* frequency at the surface of the tape will have a surface induction which is proportional to frequency. The open-circuit voltage output of an "ideal" short gap head is proportional to the rate of change of flux, or in other words proportional to frequency. Therefore, the open-circuit voltage of the "ideal" short gap head is proportional to surface induction. What this means regarding the article is that all curves labeled "surface induction" and discussions of those curves show an error of 6 db/octave. The article

would be correct if the words "surface flux" were inserted everywhere "surface induction" appears.

An error of a similar nature appears in one portion of the NARTB Recording and Reproducing Standards of June, 1953, and the proposed standard of the CCIR (Doc. 789-E, 4 October, 1953). This error is being acted upon by the respective bodies and will be corrected in the near future.

The names of the members of the Task Group which prepared the Proposed AES Disk Standard were omitted in Vol. 2, No. 1. The members of the Task Group on the Proposed AES Disk Standard are: Theodore Lindenberg, Chairman, Pickering & Company, Inc.; William S. Bachman, Columbia Records, Inc.; Charles Lauda, Decca Records, Inc.; Avery Lockner, Reeves Sound Studios, Inc.; Robert C. Moyer, RCA Victor Division; Ralph A. Schlegel, WOR Recording Studios; Edward H. Uecke, Capitol Records, Inc.

Future Meetings

Acoustical Society of America

The forty-seventh meeting of the Acoustical Society of America will be held at the Hotel Statler, New York City, June 23-26. Highlights of the technical program include: (1) two sessions devoted to round table panel surveys of progress in all branches of acoustics; (2) an evening session at the Acoustics Laboratory of Columbia University, including an inspection of technical exhibits; (3) a morning technical session on large room acoustics and related topics at Radio City Music Hall followed by attendance in specially reserved seats at the regular Music Hall performance. Three sessions will be devoted to contributed papers.

American Standards Association

The Fifth National Conference on Standards, sponsored by the American Standards Association (industry, national engineering associations and technical societies, consumer groups) will be held November 15-17 at the Hotel Roosevelt, New York City.

International Electrotechnical Commission

Seven hundred electrical technical experts from twenty-nine countries and the United States will attend the fiftieth anniversary meeting of the International Electrotechnical Commission to be held on the campus of the University of Pennsylvania, Philadelphia, September 1-16. The American Standards Association is the group through which U. S. participation in the event is being carried on. The delegates will hold 226 morning and afternoon sessions in which they will work on international standards in the fields of electric light, power, and communications.

F. Sumner Hall, Inc., Moves

F. Sumner Hall, President of F. Sumner Hall, Inc., has announced the move of his plant to Amityville, Long Island. Formerly located in mid-Manhattan, it is now housed in a larger building and consequently has been able to expand its facilities. The company manufactures jacks, jack panels, plugs, low-voltage power supplies and patch cords. Mr. Hall is a past president of the AES.

More on Audiology

Although the news item in the last issue of the *Journal* concerning the Bachelor of Science degree offered in audiology at the Los Angeles State College of Applied Arts and Sciences stated that it is believed to be the only degree of its kind, there are other colleges and institutions offering similar programs, if not the degree itself.

Among these is the Training College at Central Institute for the Deaf, St. Louis, Missouri. For many years, the Training College has offered courses at the undergraduate level, leading to the degree, which, although it is not called a degree in audiology, covers the same subject matter. Included among its faculty are Dr. Hallowell Davis, co-author with S. S. Stevens of the book *Hearing: Its Psychology and Physiology*, and editor of the book *Hearing and Deafness*; Dr. Ira J. Hirsh, author of the recent McGraw-Hill publication *The Measurement of Hearing*; and the Director of Central Institute for the Deaf, Dr. S. R. Silverman, who is also Professor of Audiology at Washington University.

The Institute carries on an extensive research program in noise, noise control, and equipment problems, sponsored and supported by such agencies as the National Institute of Health, the Veterans Administration, the U. S. Air Force, and the Office of Naval Research. It also is the location of the Armed Forces National Research Committee on Bioacoustics.

Report from Los Angeles

Officers elected by the Los Angeles chapter to serve for the year 1954 were as follows: Chairman, Herbert E. Farmer; Vice-Chairman, Alan Wolff; Secretary, Daniel H. Weigand; Treasurer, Olin Dupy. A new ruling was enacted at this election which would cause the newly elected officers to take office in February, thus allowing the present officers to complete the Audio Fair and install the new officers at a banquet to be held at the Fair.

It was decided that a new approach to the year's programming will be tried. This new approach will take the form of a number of field trips to various points of interest within the audio field. The first of these trips was held on the February meeting night at the Allied Record Manufacturing Company, where the group was treated to a complete tour through the facilities. A few of the other field trips planned will include a trip to Radio Recorders, and a tour of manufacturing plants with Berlant Associates and Altec Lansing on the list at present. A discussion on tape editing will be held at the American Broadcasting Company. Program Chairman for the year is Sidney M. Alder.

The Papers Committee under Alan Wolff is already gathering material for next year's Audio Fair. The office of Publicity Chairman is being incorporated into the office of Papers Chairman in the interest of greater efficiency and economy of time.

An attempt is to be made to get a strong Standards Committee formed and to prepare some drafts for proposed standards for submission to the local and national AES groups.

Reminiscing over the year 1953 brings to mind the most memorable event of that year. This event, in the minds of all out here, was the highly successful "Audio Fiesta Los Angeles." Official attendance was higher than 18,000, with an unofficial estimate made by the local Fire Department running 50% above the official figure.

Easily the hit of the show was the AES showing of "Shy Cy meets HiFi," produced by Jack Mullen. The production played to a capacity house every 30 minutes. So successful was the production that requests have been received for the show to be played at other functions. The basic idea was to acquaint the many thousands of people at the show with a few fundamental things to keep in mind when viewing high-fidelity equipment.

The technical sessions were, in themselves, highly successful with each paper being well received by a sizable audience. Several new pieces of equipment were introduced, including a new idea in motor design which makes use of a hollow shaft with a rotor at one end to blow air through the heated core, thereby reducing the heat problem. A new method of tape duplication was discussed with a look at the future for this field.

As the three-day stand came to a close, both engineers and public had a feeling of a job well done.—*Sidney M. Alder*

Columbia University Acoustics Lectures

The Acoustics Laboratory at Columbia University has initiated a series of public lectures by outstanding men in the various fields of acoustics. According to the Director of the Laboratory, Professor Cyril M. Harris, the next lecture will be given by Mr. Frank Massa of the Massa Laboratories, Inc., Hingham, Mass., who will discuss the fundamentals of transducer design for the sonic and ultrasonic ranges. Mr. Massa, a recognized authority on transducer design, is author of "Acoustic Design Charts" and co-author of the book "Applied Acoustics."

His lecture will be given on May 6th at 7:45 P.M. at the Casa Italiana, Columbia University, 117th Street and Amsterdam Avenue, New York. Previous lecturers in this series have included: W. A. Jack, Chief of the Acoustic Engineering Section of the Johns-Manville Research Center, who spoke on acoustical research and development in the building industry; H. F. Olson, Acoustical Research Director at the RCA Laboratories, who discussed some of the modern aspects of sound recording and reproduction; G. E. Peterson, formerly with the Bell Telephone Laboratories and now at the University of Michigan, who discussed the psychophysical nature of speech and language and recent developments in the analysis of speech; F. A. Firestone, Editor of the *Journal of the Acoustical Society of America*, who presented a new point of view for consistent analogous circuits between mechanical, electrical, and acoustical systems; and W. A. Munson of the Bell Telephone Laboratories, who discussed psychophysical measurements in acoustics and presented results of recent research in psychoacoustics.

Eighth Annual Convention, American Society for Quality Control

The Eighth Annual Convention of the American Society for Quality Control will be held in St. Louis, Missouri, on June 9–11, 1954. Headquarters for this convention will be the Jefferson Hotel. The technical sessions will be held at Kiel Auditorium. The program will consist of 72 sessions, which will include 67 technical sessions and 5 sessions devoted to plant tours. The Chemical and Textile Divisions are participating, as are the Aircraft, Automotive, Electronics, Metals, and Operations Research Committees. In addition, the more recently organized Business Operation Committee has a program, and a series will be presented by the Basic Research Committee.

There will be space for the largest number of exhibitors in the history of the convention, and most of it will be filled. There will be a book booth in the form of a spacious lounge with plenty of easy-chairs. Books on all phases of quality control and many related subjects will be on sale. Several authors are scheduled to be on hand.

Many social events are planned for the evenings, and, for those who plan to bring their wives, a ladies' program has been arranged. Registration blanks and further information may be obtained from: Mr. U. C. Gramsch, Registrar, 8th Annual A.S.Q.C. Convention, P.O. Box 4436, Wade Station, St. Louis 15, Missouri.

Section Meetings

Cincinnati

Chairman: Charles Boegli
Secretary: Joseph Owen, 3242 Woodburn Avenue, Cincinnati 7, Ohio
Papers: "Effect of High-Frequency Pre-Emphasis on Groove Shape," Jerry B. Minter and Aldo R. Miccioli, read by Charles Boegli, Cincinnati Research Co., November 15, 1953.

"Hearing the Orchestra" and "The Sound Man" (films), November 15, 1953.

"A High-Quality Low-Cost Amplifier," Charles Boegli, Cincinnati Research Co., February 25, 1954.

Columbus

Chairman: J. E. Anderson
Secretary: William E. Parker, 1271 Republic Ave., Columbus, Ohio
Paper: "RC Networks," Edwin D. Sisson, Bell Sound Systems, Inc., December 10, 1953.

Los Angeles

Chairman: Herbert E. Farmer
Secretary: Daniel H. Weigand, 3122 West 152 Place, Gardena, California
Papers: "Design of an Electrostatic Loudspeaker," Theodore Lindenberg, Charles E. Smiley, and Jerry B. Minter, read by Allan Bodge, Audio Devices, Inc., December 29, 1953.

"Golden Ear or Tin Ear?" Harry Bryant, Radio Recorders; Clayton Stevens, Allison Laboratories; December 29, 1953.

"The Design Considerations of Audiometric Equipment," Ralph Allison, Allison Laboratories, January 26, 1954.

"Magnetic Video Tape Recorder," John T. Mullin, Bing Crosby Enterprises, January 26, 1954.

"Record Manufacturing," and tour of Allied Recording Plant, Samuel Salzman and Jack Wagner, Allied Record Mfg. Co., Inc., February 23, 1954.

New York

Papers: "A Low Impedance Bus Distribution System," Stephen F. Temmer and Rein Narma, Gotham Recording Studios, January 12, 1954.

"Record Manufacturing Changes Induced by the Evolution of the Long Playing Record," K. R. Smith, K. R. Smith Division, Allied Record Mfg. Co., February 9, 1954.

"Experiences in Multichannel Recording," W. D. Fling, Cinerama, Inc., March 9, 1954.

San Francisco

Chairman: B. H. Smith
Secretary: Wallen W. Maybeck, 2751 Buena Vista Way, Berkeley 8, California
Papers: "Magnetic Recording Tape," William C. Courtney, Minnesota Mining & Manufacturing Co., October 12, 1953.

"The Cinemascope Audio System," William B. Saeman and John Leslie, Ampex Electric Corp., December 14, 1953.

"Low-Frequency Behavior of Enclosed Loudspeakers," Robert C. Acker, Radiation Laboratory, University of California, January 11, 1954.

"Amateur Sound Recording," Vincent Salmon, Stanford Research Institute, February 8, 1954.

"Some Audio Measurement Problems," Bernard M. Oliver, Hewlett-Packard Co., March 8, 1954.

RENSSELAER POLYTECHNIC INSTITUTE

Chairman: Charles R. Wood
Secretary: John D. McKendree, 30 Eighth St., Troy, New York
Papers: "Loudspeaker Impedance Measurements," William Webb, student, February 23, 1954.
"The Modern High-Fidelity Recording," Frank Gioca, student, March 10, 1954.

Members

Baghurst, Walter F., 637 E. Broad St., Souderton, Pa.
Brougher, Roy Marcellus, 3737 Bellaire Blvd., Houston 25, Texas
Brown, C. Scott, 2513 Lake Drive, S.E., Grand Rapids, Mich.
Bubbers, John J., 24 Jefferson Ave., Massapequa Park, N. Y.
Campbell, Charles Allan, 624 Nathan Hale Road, West Palm Beach, Fla.
Carson, Robert Hardy, 1313 49th Ave., S.E., Washington 27, D. C.
Cheney, John F., 345 Brazilian Ave., Palm Beach, Fla.
Courtney, William G., 450 Alabama, San Francisco 10, Calif.
Edgerly, Clement Bradford, 11660 Chandler Blvd., North Hollywood, Calif.
Flan, Anthony, 1050 Hinman Ave., Evanston, Ill.
Futterman, Julius, 523 W. 112th St., New York 25, N. Y.
Goldman, Leslie A., 588 5th Ave., New York 19, N. Y.
Goodwin, Earl V., 5120 Highland View Ave., Los Angeles 41, Calif.
Hamme, Carlton Edward, 508 W. 8th St., Erie, Pa.
Handforth, Thomas E., 6222 N. Ivar Ave., Temple City, Calif.
Harris, Cyril Manton, Acoustics Laboratory, Columbia University, New York 27, N. Y.
Hofman, J. Anton, 90-A Kirkland St., Cambridge, Mass.
Houck, Seth C., 772 Worthington St., Springfield, Mass.
Jarosik, Norman Andrew, 738 Lafayette, Buffalo 22, N. Y.
Kester, Arthur S., 3515 Addison St., Chicago 18, Ill.
Koenigsberg, Richard Alan, 26 Alexandria St., Sausalito, Calif.
Leinbach, William James, Apt. 19-F, College Village, Winston-Salem, N. C.
Levine, John J., 9 Kelley Square, Worcester 4, Mass.
Little, George Warren, 105 W. 35th St., Minneapolis 8, Minn.
Meyer, Budd M., 1435 E. 21st St., Brooklyn 10, N. Y.
Morris, Raymond Albert, 6484 North Park Ave., Indianapolis 20, Ind.
Thurston, Edward G., 2433 N. Belvoir Blvd., Cleveland 21, Ohio
Ulrich, Vinton Kenneth, 1 Treadwell Ave., Madison, N. J.
Vreeland, Walter E., 38 Southern Slope Dr., Millburn, N. J.
Woglom, William H., 198 Union Ave., Rutherford, N. J.
Zuckerman, Alfred, 29 9th Ave., New York 14, N. Y.

Associate Members

Collins, George M., 1504 Birmingham Blvd., Birmingham, Mich.
Davison, Hal Marr, Pfc., 9301 TSU-ORD D & PS Det. Box 130, Aberdeen Proving Ground, Maryland
Dixon, William Jack, 10624½ Stilson, Los Angeles, Calif.
Dunckel, Peter B., 955 Park Ave., New York 21, N. Y.
Kluge, James E., Centralab Div. of Globe Union, 900 E. Keefe, Milwaukee 1, Wisc.
Kubishi, George, 2370 Midvale Ave., Los Angeles 64, Calif.
Larkins, Maynard J., 1641 Stratford, Westchester, Ill.
Meeker, David V., 157 Chambers St., New York 7, N. Y.
Plutt, Joseph Anthony, Jr., 3346 Delaware St., Pittsburgh 14, Pa.
Riley, Warren J., U. S. C. G. Depot—Box 3, Navy 926—c/o F. P. O., San Francisco, Calif.
Watkins, James E., Philips Laboratories, Inc., 100 E. 42nd St., New York 17, N. Y.
Wenrick, Howard P., Station A, Box 905, San Mateo, Calif.

Student Members

Arthur, Harold, 8569 Nash Drive, Los Angeles 46, Calif.
Condon, David Charles, 325 W. Baltimore, Larkspur, Calif.
Emus, Harold, 426 So. Manhattan Pl., Los Angeles 5, Calif.
Firestone, Ross Francis, 1005 E. 60th St., Chicago 37, Ill.
Glazer, Lee Berton, 117 North Vista St., Los Angeles 36, Calif.
McEwen, Charles C., 1652 Neil Ave., Columbus, Ohio
Nesting, James Wesley, 1014 Broadway, Apt. No. 2, Fargo, N. D.
Pallas, Earl A., 501 Middle Ave., Elyria, Ohio
Ratner, Allan, 42 So. Lake Ave., Troy, N. Y.
Richert, Richard Michael, 1291 Putnam Ave., Brooklyn 21, N. Y.
Ward, Gray Douglas, 123 Washington Ave., Charlottesville, Va.

Change of Grade—Members

Augspurger, George L., 7041 North 14th Place, Phoenix, Ariz.
Berry, George M., 8926 Eames Avenue, Northbridge, Calif.
Coate, Forrest M., 9603 Ocean Gate Ave., Inglewood, Calif.
Collins, Benjamin F., Jr., 4324 Via Azalea, Palos Verdes, Calif.
Ingall, William Elfric, 1500 Morada Pl., Altadena, Calif.
Mackechnie, Gordon M., 3161 Menlo Drive, Glendale 8, Calif.
Wolff, Allan L., 6601 Romaine St., Hollywood 38, Calif.

Change of Grade—Associate Members

Edsall, Samuel C., 120 Roxbury Road, New Britain, Conn.
Wagner, Burton Francis, 182 Kingsley Road, Burnt Hills, N. Y.
Waltz, Manford W., Northrop Aircraft, Inc., Patrick Air Force Base, Fla.

Resigned

Golden, Ward G., 215 Langdon Ave., Mt. Vernon, N. Y.
Orange, Murray, 1311 Beach Avenue, Bronx 72, N. Y.
Thurston, William Robert, Jr., c/o General Radio Co., 90 West Street, New York 6, N. Y.
Yearsley, Earle Theodore, 1517 Avon Pl., Pittsburgh 21, Pa.
Kuenzli, Walter A., c/o Crosley Division AVCO, Arlington St., Cincinnati 25, Ohio
Goldin, Hyman, 394 Avenue Road—Apt. 402, Toronto, Ont., Canada

Audio Engineering Society—Second Annual West Coast Convention—1954
Los Angeles, California

PROGRAM OF TECHNICAL SESSIONS

Thursday Morning—February 4, 1954

TRANSDUCERS

Chairman: HERBERT E. FARMER
USC Dept. of Cinema

10:00 AM **The Floating Diaphragm as a Low-Frequency Radiator**
WILLIAM C. BENJAMIN, William C. Benjamin Sound Co., Mt. View, Calif.
This paper describes the Benjamin speaker system, a method of expanding the radiating area through the use of a floating diaphragm. This diaphragm also acts as an acoustic filter which makes it possible to achieve a much smoother response and at the same time reduce distortion.

10:30 AM **Discussion of the Proper Selection of Mass, Compliance, and Dampening in a Phono Pickup**
EARL GRANT, Statham Laboratories

11:00 AM **A Unidirectional Microphone Utilizing a Variable Distance between the Front and Back of the Diaphragm**
A. M. WIGGINS, Vice President for Engineering, Electro-Voice, Inc., Buchanan, Mich.
A unidirectional pressure-gradient microphone is described which utilizes a front-to-back distance varying inversely as the frequency. The varying front-to-back relationship is achieved by utilizing two sound entrances with frequency discriminating parameters. One entrance is situated at a large distance from the front surface of the generating element while another entrance is placed directly behind the sound responsive element. With this microphone desirable characteristics can be obtained which would not be possible in the conventional cardioid type having a fixed front-to-back distance. The principle of its operation is described and compared with that of the conventional fixed distance cardioid microphone.

11:30 AM **Survey of Flux-Responsive Magnetic Reproducing Heads**
OTTO KORNEI, Clevite-Brush Development Company, Cleveland, Ohio
A magnetic reproducing head which generates a signal voltage substantially proportional to the magnitude of the intercepted magnetic flux is commonly referred to as a flux-responsive or magnetostatic head. The fundamental model of operation, the different approaches to practical solutions, and the characteristic features of this type of head are described in general terms. The explanations are illustrated by a number of cases which have been either proposed or practically executed by various organizations and investigators. A pertinent bibliography is given.

12:00 M **The Mechanics of Good Loudspeaker Design**
ABRAHAM COHEN, University Loudspeakers, Inc., White Plains, N. Y.
Although a loudspeaker is invariably associated with electronic equipment, the degree to which it performs acoustically is strictly a matter of mechanics. Those characteristics of the loudspeaker which are a measure of the quality of its reproduction such as frequency response, polar distribution, acoustic power-handling capacity, and cleanliness of response may all be resolved through the general theory of mechanical structures in terms of physical stresses and strains. The acoustic design objectives for a given loudspeaker will determine the mechanical and structural details of the rest of the assembly, including the vibrating structure with its centering devices, the supporting basket, and the magnetic system. Since a loudspeaker must work with a baffle, the baffle itself becomes a legitimate component of the loudspeaker system, and the mechanical details of its construction, regardless of the acoustical principles involved, will greatly affect the low-frequency performance of the system. In like manner the decorator's touch in choice of grill cloths may seriously alter the high-frequency efficiency of the system.

Thursday Afternoon—February 4, 1954

AMPLIFIERS AND EQUIPMENT

Chairman: BOYD MCKNIGHT
North American Aviation

1:30 PM **A Critical Analysis of Feedback Action**
HAROLD KLIMPEL, 3615 Los Flores Blvd., Lynwood, Calif.
It is the intent of this paper to analyze briefly the simple, fundamental theory underlying the application of feedback to any amplifier while at the same time pulling back the curtain that has left many with false impressions of how feedback accomplishes what we know about it in its present state. To develop equations applicable to feedback amplifiers, an amplifier without feedback is reviewed and then modified to include a given amount of current feedback, which, it will be shown, affects the voltage equations of both input and output circuits. The over-all gain with current feedback can be proved to be $Acf = \frac{A(1\text{-}K)}{(1\text{-}AK)}$, where A is gain without feedback and K is percentage of output feedback. Using the maximum amount of current feedback provides one with a cathode-follower circuit in which, the author contends, there is no "low impedance generator" possibility. It will be proved that feedback, either positive or negative, never changes the plate resistance or amplification factor of any tubes in a feedback loop, the only impedance change occurring in the input circuit. This fact, together with a beta sign that is never negative, will be the basis for carrying the discussion to include voltage feedback. The author will also prove that there is no difference between current and voltage feedback in so far as its relation to output stabilization and other changes in amplifiers with feedback is concerned.
Closing remarks will center about an amplifier circuit with multiple feedback paths to demonstrate the improvement of output regulation with feedback potentials as well as an accurate determination of noise

and distortion voltage with applied feedback by the use of equations as developed previously.

2:00 PM **A Power Amplifier Capable of Providing Optimum Damping for Loudspeakers**
G. H. GREY and G. W. DOWNS
The response of low-frequency loudspeakers is affected by the source impedance represented by the power amplifier with which they are used. The optimum value of source impedance is determined by a number of factors which include the efficiency of the unit, the nature and size of the enclosure (or horn), and the room conditions. Except for very inefficient loudspeakers, this impedance is not zero as is commonly asserted. A great many good loudspeakers are now operated under conditions that result in less than optimum performance. A power amplifier has been designed and built which provides means of making the adjustment of source impedance necessary to achieve optimum performance. This adjustment can be made independent of the other factors involved in the combined use of the loudspeaker and power amplifier.

2:30 PM **A Versatile Audio-Frequency Oscillator**
C. L. STEVENS, Allison Laboratories, Puente, Calif.
An L-C oscillator capable of delivering adequate audio frequency power output for test purposes without further amplification. The frequency may be warbled a fixed per cent at any operating frequency. The frequency may be pulsed without key clicks or appreciable frequency change.

3:00 PM **Component Parts for High Fidelity**
DR. HARRY F. OLSEN, Radio Corporation of America

Friday Morning—February 5, 1954

DISCUSSIONS AND APPLICATIONS

Chairman: CARL SHIPMAN
Radio Corporation of America

10:30 AM **Some Considerations in Writing Transformer Specifications**
G. GRAHAM and F. SUFFIELD, Triad Transformer Corp.
A discussion of some of the requirements from the customer of the transformer industry in order to allow design of components that will achieve the desired end results. Subjects covered will be power components such as: chokes and transformer, audio components including input, interstage, and output transformers, as well as special items such as autotransformers, isolation and matching units, and related elements.

11:00 AM **The Laminated Magnetic Sound Track**
ROBERT HOPKIN, Bing Crosby Enterprises, Inc., Hollywood, Calif.
The different methods of obtaining magnetic sound on standard motion picture film will be discussed, and a demonstration will be given comparing laminated magnetic film to standard optical film.

11:30 AM **Dependable Production Line Measurement of Harmonic Distortion down to 0.001%**
PHILLIP R. GEFFE, Chief Filter Engineer, Triad Transformer Corp.
The usual methods of measuring harmonic distortion in industry are inconvenient, expensive, and subject to error. A superior method is outlined employing passive networks.

12:00 M **The Tower of Audio**
JOHN T. MULLIN, Bing Crosby Enterprises, Hollywood, Calif.
The current interest in high-quality sound in the home is centered about that field of business described by the term "high fidelity." It is not the purpose of this paper to define this and other audio terms discussed but rather to speculate on the confusing changes currently taking place in the meaning of these words, whither they take us, and with what results.

Friday Afternoon—February 5, 1954

TAPE RECORDING EQUIPMENT

Chairman: RICHARD HASTINGS
Ealy and Hastings

1:30 PM **Tape Duplication in Production Quantities**
RUSS TINKHAM, Ampex Electric Corporation, Redwood City, Calif.
A discussion of a newly designed system which produces up to 10 hours of playback material in 1⅞ minutes.

2:00 PM **Practical Considerations in the Equalization of Magnetic Recorders**
RICHARD HOSKIN, Berlant Associates, Los Angeles, Calif.
A discussion of the problems encountered in designing and producing electronic equipment for use with magnetic tape transports. The problem of equalization standards in the industry will be discussed, with comment from the floor invited.

2:30 PM **A New Professional Quarter-Inch Tape Recorder/Reproducer**
WILLIAM V. STANCIL, President, Stancil-Hoffman Corporation
A discussion of the design and production of a high-quality tape recorder for use in industrial and professional recording fields. Factors relating to consistent low flutter and wow and good speed regulation. Hysteresis synchronous motor design for the drive system. Torque sensitive motor design for the feed and takeup reels. Head design consideration for wide frequency response and large dynamic ranges. Operational controls for safe and dependable tape operation for both recording and editing.

Saturday Morning—February 6, 1954

RECORDING

Chairman: DANIEL H. WEIGAND
USC, Dept. of Cinema

10:30 AM **Motion Picture Sound Recording at USAF Lookout Mountain Laboratory**
HOWARD TREMAINE, USAF Lookout Mountain Laboratory, Hollywood, Calif.

The body of the paper describes the recording facilities at the USAF Lookout Mountain Laboratory and special equipment developed for their particular requirements.

11:00 AM **Sequential Recording with One Tape Recorder**
RICHARD HOSKIN, Berlant Associates, Los Angeles, Calif.
Technique of making multiple or additive recordings with the use of an adaptor and rearranged recording and playback heads.

11:30 AM **Monogroove Stereophonic Disk Recording**
JOHN T. MULLIN, Bing Crosby Enterprises, Hollywood, Calif.
The day seems to be fast approaching when the high-fidelity enthusiast will demand the additional advantages of stereophonic reproduction. "Stereo" radio broadcasts and special recordings have been made available which readily acquaint him with its benefits. A new type of compatible disk record is described which contains simultaneous recordings for two-channel stereophonic applications, yet the economy of running time is as great as that of the customary single-channel disk.

12:00 M **Stereophonic Motion Picture Sound**
ROSS SNYDER, Ampex Electric Corporation, Redwood City, Calif.
With stereophonic sound now becoming popular in the motion picture industry, this paper will discuss the method and equipment used to achieve true stereophonic reproduction.

Saturday Afternoon—February 6, 1954

NEW DEVELOPMENTS

Chairman: ROBERT HOPKIN
Bing Crosby Enterprises, Inc., Hollywood, Calif.

1:30 PM **Etched Circuits for Audio**
K. B. HOWARD, Tri-Dex Electronics
Etched circuits are practical for short-run production and have advantages in cost, appearance, accuracy, and ease in servicing. Data are presented on materials, electrical properties, and layout. Factors affecting cost are given. Practical use on the line is described.

2:00 PM **Transistors—Their Manufacture and Application to Audio Circuitry**
L. E. KING and CARLOS ALDERETE, Hydro Aire, Burbank, Calif.

2:30 PM **A Modular Chassis and Its Effect on Design**
J. M. DILL, UM&F Manufacturing Corp.
A description of a new type of chassis for use in the electronic field that lends itself to changes during a design problem. Its feature of expansion in any direction places in the designer's hands a means of simple, low-cost prototype construction. Where a necessary addition of one or more large components would, in many cases, make obsolete the present chassis, it is now possible, using modular construction, to expand the chassis to a larger size, or change its shape so that only a small percentage of work need be discarded. This of course means that an initial prototype will be prepared sooner and at a fraction of the normal costs.

Audio Aspects of the SMPTE 74th Convention -- A Review

JULIUS POSTAL

Tele-Science Productions, New York, New York

Introduction

MOTION-PICTURE audio received major treatment at the 74th Semi-Annual Convention of the Society of Motion Picture and Television Engineers, held in New York City, October 5–9, 1953. This was to be expected because the commercial introduction of wide-screen processes (and also 3-D) has been accompanied, in most cases, by changes of one kind or another in the systems and techniques used to record and reproduce the sound.

The present piece will attempt to summarize and comment on most of the SMPTE papers and discussions which dealt with multichannel magnetic reproduction systems, "button-on" magnetic soundheads, magnetic head wear, the basic principles of binaural and stereophonic sound, equalization, magnetic projectors, lip synchronization equipment and techniques, etc.

Any viewpoints or "slants" which appear herein, unless otherwise attributed, are those of the present writer as an individual and are not necessarily shared by the other editors of the *Journal of the Audio Engineering Society*.

The present writer wishes to express his thanks to the Society of Motion Picture and Television Engineers and particularly to Victor H. Allen, Editor of the *Journal* of the SMPTE for his excellent cooperation.

SOME HISTORICAL ANTECEDENTS OF STEREOPHONIC SYSTEMS

Certainly, the "binaural" idea is not new. Augustus Rosenberg patented two-channel sound recording for "true binaural" reproduction in England back in 1911.

As is well known, multichannel sound was dramatically presented by the Bell Telephone Laboratories in the 1930's. And RCA and the Walt Disney organization joined forces just prior to World War II to bring us the multichannel photographic-optical system known as Fantasound, with its strong emphasis on "enhancement" by means of manipulation (*after* the making of the original recordings) and the use of control information to extend the dynamic range during playback.

Nor is the idea of *simulating* "binaural" or "stereophonic" effects entirely new. J. Küchenmeister set forth the use of delay for this purpose in a British patent dated 1924; about a year later, in a separate British patent, he applied this same concept to *film* recording. And in 1939, at the Detroit Convention of the SMPTE, William H. Offenhauser, Jr., and the late J. J. Israel demonstrated a system (which has been patented) for deriving a simulated "stereophonic" recording from an ordinary single-channel recording.

"COMPATIBLE" THEATER SYSTEMS

The attempts to give the screen "a new dimension" seem to be characterized by two main tendencies:

One approach tries to make the new system "compatible" with the conventional system so that at least the basic theater plant can be used (although with modifications and not necessarily inexpensive ones). This particular philosophy is typified by an attempt to cram more picture and sound information into the same film area while running the film at the usual speed of 18 ips.

Obviously, this approach places increased demands upon the resolving power of the film and also upon the camera and projection optics. New demands are made on the projector transport mechanism in the matter of placing a steady picture on the screen and moving the multiple sound tracks past the respective scanning points at a constant rate and with a minimum of lateral weave. Since a greater screen area must be covered, more light is needed, with the consequence that measures must be taken to hold down dimensional distortion of the film resulting from heat absorption at the picture gate. Moreover, as the tracks become narrower, the problem of maintaining a good signal-to-noise ratio becomes more difficult.

It is not inconceivable, of course, that finer-grained emulsions will be brought to bear upon the problem of resolution and that ways and means will be found to increase the steadiness of the projected picture as well as to reduce "breathing" effects resulting from the rapid absorption of heat at the picture gate. Nor has the last word been spoken with respect to oxides, magnetic head wear, or the problem of maintaining good contact between the oxide and the head.

Under the heading of "compatible" systems comes Perspecta Sound, which is able to derive what appears to be a modified wide-screen image—with compromises—either from films shot in the CinemaScope aspect ratio or films photographed in the *standard* aspect ratio of today.

The audio part of Perspecta Sound, as detailed below, is a single photographic-type sound track to which control signals have been added during re-recording. In short, the release print does not carry a multichannel recording in the

sense of several *physically different* tracks: What happens is that, with the help of the control information, a multichannel simulated stereophonic *playback* is derived from the single physical track.

The economic advantages of such a system are immediately apparent. The only attribute of stereophony used here, however, seems to be that of intensity-difference manipulation among the three *playback* channels. It is difficult to see how such a system could simulate the effects of arrival-time and quality differences, phase displacement effects, or, for that matter, spatial-orientation effects resulting from pick-up-room acoustics, without going into a fairly complex system of encoding and decoding control information.

The fact that Perspecta Sound appears limited to intensity-difference manipulation does not of itself preclude theatrically effective presentations. Neither the "legitimate" stage nor the movies—nor, for that matter, *any* "dynamic" art form—has ever depended on *exact* duplication of reality, either visually or aurally, to create its dramatic effects.

NON-"COMPATIBLE" SYSTEMS

The second approach gives scant heed to the matter of "compatibility." Here, a larger screen image is secured by markedly increasing the film area. In one system, notably Cinerama, this is accomplished by running three separate projectors in synchronism and by making each individual picture frame one-and-a-half times as high as the conventional standard 35-mm frame.

In order to reduce the sensation of peripheral flicker somewhat—which could be aggravated for the spectator by the very "engulfing" nature of the Cinerama screen—the three films are run at *26* frames per second instead of the standard 24 frames per second. The increase in frame height and frame repetition rate together yields a film speed of some 30 ips for *both* the picture and the sound tracks.

As a matter of fact, the Cinerama sound tracks travel at a higher linear rate than do the tracks of any other commercial film system. This, it is claimed, makes it no problem at all to maintain a "flat response" up to 12,000 cps. The designers of Cinerama feel that good reproduction of the upper audio frequencies—including sibilants—is essential to "stereophonic realism."

Moreover, the Cinerama team decided quite early in the game that the three channels which have become customary in stereophonic theater systems would not be adequate with an extended screen like that of Cinerama. It was feared that the use of only three channels might result in "gaposis," particularly for spectators in the front rows of the theater. Consequently, the system today uses seven sound tracks (with room, all told, for fourteen) and five speaker assemblies behind the screen. Additional speaker assemblies located *away* from the screen can be used as the need arises.

AN INTERMEDIATE APPROACH

A third approach, which falls somewhere in between the two principal approaches set forth above, is a system in which the original "shooting" is done with a frame of about *twice* the area of the present 35-mm frame. This is achieved by moving the film in the camera *laterally* (as in double-frame 35-mm *still* cameras—the so-called "miniature" cameras) instead of *vertically* as in conventional motion-picture cameras and projectors. During the printing process, each double frame of the negative is reduced optically and rotated 90 degrees—by means of prisms, no doubt—so that the ultimate release print can be run in a standard theater projector with a conventional pulldown.

It should be noted that this approach does not necessarily affect the sound track or sound tracks one way or the other, although analogous reasoning could be applied in making the original production recordings and in the subsequent re-recording steps right up to the final release print: A speed higher than 18 ips could be used. True, the effect of cumulative high-frequency losses during the various re-recording steps could probably be reduced and the frequency range of the ultimate release print extended. But, then, extension of the audio bandwidth for its own sweet sake has never been advocated generally in the film industry; there are too many other factors involved.

Time, in combination with the day-to-day grind of film production and exhibition, will decide which of these systems is to survive or whether *all* of them will be able to co-exist peaceably.

EQUALIZATION

A proposal for more high-frequency pre-emphasis in magnetic recording for films stirred up lively pros and cons, as any discussion on equalization is apt to do in the film industry. The idea met with considerable opposition, as do practically all proposals for increased high-frequency boost in the motion-picture field.

Nor was a warm reception accorded the idea of setting up a standard *recording* characteristic for magnetic sound on film to complement the proposed new *reproducing* characteristic: Neither the motion-picture industry as a whole nor the SMPTE has ever considered a standard *recording* curve practical. The traditional reasons for this—which still apply, in this writer's opinion—will be detailed later on in a separate piece.

It can be said categorically that no segment of the recording field has had as much varied experience with equalization problems as the film business. Leaning heavily on what had already been worked out both theoretically and practically in telephone practice, film people carried the matter to a high point of development early in the history of motion-picture sound recording. Where but in the film busi-

ness is it necessary to take into account simultaneously factors like "dialogue equalization," "effort equalization," compensation to offset the frequency-discrimination effects attendant upon the use of compressors, compensation for losses occasioned by slippage between the negative and the raw stock in the printer, "scanning slit losses" in the projector and compensation for the boominess and/or absorption characteristics of many theaters, and the like?

Despite all these factors—and others, too—a remarkable degree of standardization has developed over the years. A given sound track played in *one* neighborhood theater is apt to have pretty much the same frequency characteristic, as far as the spectator is concerned, as the same track played in *another* neighborhood theater in a *different* city.

One of the by-products of the give-and-take on equalization was the notion, new to many sound engineers, that an equalization characteristic which is suitable for use with *one* language may exact considerable penalties in the way of signal-to-noise ratio when used in recording *another* language. This, too, is mentioned below.

ONCE AGAIN THE "QUEST FOR CONSTANT SPEED"

The advent of quadruple-track magnetically striped systems has once again brought the problem of uniform film motion to the fore. It has been necessary, because of the introduction of the new, narrower, CinemaScope-type perforations and the extra friction occasioned by the presence of the magnetic stripes, for the companies making the new "button-on" or "top-hat" magnetic reproducers to give careful heed to the mechanical design of transport mechanisms. Obviously, neither the picture nor the sound would benefit were additional disturbances introduced into film motion. It would be unfortunate, too, were a change in sprocket or tooth design to cause an increase in sprocket-hole wear. Any stretching or damage of the perforations tends to be cumulative and might ultimately affect the steadiness of the projected picture as well as contribute to lateral weave as the four narrow sound stripes pass over the four respective heads of the magnetic pickup.

It should be emphasized that film technology is no stranger to the "quest for constant speed," as it was called by E. W. Kellogg many years ago. A great deal of what is known today about transporting the medium past the sound-scanning point *smoothly* was evolved in the film industry—by Kellogg at RCA and by W. J. Albersheim and C. C. Davis at Bell Labs. It is no wonder, then, that flutter, sprockets, sprocket teeth, and sprocket-hole dimensions received detailed attention in the SMPTE papers and discussions.

MAGNETIC HEAD WEAR

Magnetic head wear also came in for considerable discussion. It was felt that in the theaters, where millions of feet of oxide-coated film go over the pickups each month, the replacement of multiple-headed units could become a significant operating expense, particularly in the *smaller* theaters.

John G. Frayne noted that the optical scanning arrangements in conventional projectors do *not* have a tendency to wear out (except that exciter lamps have to be replaced occasionally). This was more than could be said for magnetic heads, he indicated. He conceded, however, that the amount of available evidence on magnetic head wear at that moment was too small for definitive conclusions one way or the other. This was the general consensus.

STANDARDS AND THE SMPTE

The audio field may well take note that, as always, the SMPTE continues to grind out standards, working up proposals for new ones or preparing modifications of existing ones as the need arises. The film industry as a whole and various technical groups *outside* the industry habitually look to the SMPTE as a source and fountainhead of standards; it is rarely necessary to *sell* the need for standardization to film people. They understand the economics of it quite well.

It is deplorable that so little official standardization work is going on in the audio field—particularly in that segment of the field known as "high fidelity." Standardization is desperately needed in audio, if only for purposes of interchangeability and manufacturing economics, let alone the needs of the consumer.

Reproducing Equipment for Quadruple-Stripe Magnetic Stereophonic Film Systems

Three separate papers were presented at the SMPTE Convention describing reproducing equipment developed by the General Precision Laboratory, Inc., the Westrex Corp., and RCA for stereophonic systems of the CinemaScope type. All the units described were of the top-mounting variety and were variously referred to as "top-hat" reproducers, "sandwich" reproducers, "button-on" reproducers, etc. Some standardization will ultimately be needed in the nomenclature used to describe these systems, just as there is an urgent need for it in stereophonic sound, 3-D pictures, wide-screen processes, and the like. The need for such standardization is almost universally recognized, but, when it gets down to the day-to-day detail work, the prevailing idea seems to be to "let George do it."

Actually, the top-mounting idea is not new at all, any more than wide screens or stereophonic sound. The original top-mounting soundheads arrived on the scene in the late 1920's in connection with the introduction of photographic sound tracks. Patents for wide-screen processes of one sort

or another date back to at least 1896. And stereophonic systems, as will be shown in this Journal in a forthcoming annotated bibliography on stereophonic and binaural systems by William H. Offenhauser, Jr., and Julius Postal, antedate the development of practical electronic amplification systems. It is well-known that the motion-picture industry became actively interested in these systems and devices only with the advent of widespread home television.

THE GENERAL PRECISION MAGNETIC SOUNDHEAD

The top-mounting soundhead designed by the General Precision Laboratory, Inc., for the quadruple-stripe CinemaScope-type sound tracks was described by S. W. Athey, Willy Borberg, and R. A. White.[1]

In the early part of 1953, said the authors, Twentieth Century-Fox demonstrated the wide-screen motion-picture process now known as CinemaScope to film-industry groups and asked equipment suppliers to develop methods for putting a multitrack stereophonic sound record on the same release film with the picture.

Originally, Twentieth Century-Fox had proposed that three 50-mil magnetic stripes be applied to the release print in the area adjacent to the sprocket holes of standard 35-mm film.

This proposal, after modification, eventually became the basis for the present CinemaScope film. In time, the sprocket holes were narrowed. This yielded space for a fourth or "effects" track (the "audience-surround" track) and permitted widening of the three main tracks to 63 mils each. Otherwise, the original proposal was retained.

According to Messrs. Athey, Borberg, and White, General Precision made the first single-film stereophonic recordings of Twentieth Century-Fox demonstration material, using electronic facilities of a breadboard nature, assembled partly from components lent by the film company. The recording machine, per se, was actually a theater projector. The sound records thus produced were apparently the inspiration for going ahead with the development of a *commercial* system.

The magnetic soundhead ultimately evolved mounts on top of the projector head. [Actually, as the authors acknowledge, this approach is a throwback to some twenty-five years ago, when the first photographic sound-track reproducers employed in the motion-picture industry were of the top-mounting variety.—*JP*] This type of soundhead was adopted, declared the authors, so that existing theater projectors would be able to play the four-track magnetic release prints with a minimum of modification and without any interference with their ability to project conventional composite release prints having regular photographic sound tracks.

The idea of developing a *combination* magnetic-optical soundhead was considered and rejected for a number of reasons: It was felt that such a unit would, of necessity, have to be a compromise, because the magnetic sound stabilizer would have to "operate in the presence of head friction." Further, the very presence of the magnetic pickup head could easily affect performance when photographic sound was being played. [It should be noted that with the rotary-type sound drums so common in theater projectors the friction resulting from the dragging of film over a stationary head had long since been eliminated.—*JP*] It was felt, too, that any attempt to add additional parts to a standard photographic soundhead might mean crowding.

On the positive side, said Messrs. Athey, Borberg, and White, positioning of the magnetic reproducer on top of the projector was expected to yield a number of advantages: The magnetic head, which is far more sensitive to hum than an optical head, would be farther away from the strong hum fields of drive motors and selsyns. The eye-level position of the soundhead would make the film-threading process easier. And the film, as it moved past the magnetic scanning point, would not yet have been subjected to the momentary frame deformation, or buckling, caused by heat absorption at the picture gate. [In the conventional theater projector, the optical scanning of the sound track takes place at a point which is physically 20 frames *ahead* of the picture aperture. This means that the film, which has picked up a certain amount of heat energy at the picture aperture—depending on the lamp intensity, the ventilating system, and the various design factors of the particular machine—passes over the sound-scanning point about ¾ of a second later. The film makes a rapid, but not necessarily a complete, recovery from the deformation caused by the sudden heat absorption, but it is important to emphasize that significant, though usually temporary, deformation does take place. Unfortunately, a 35-mm theater projector, with color film in the picture gate and 150 amp or more on the arc, is able to place many Btu's on a film frame, even though we filter the light from the arc as best we can. The thermal coefficient of expansion of the emulsion is about eight times that of the film base; the result is that the release print, when heated, acts like a bimetallic strip. The film, on entering the picture gate cool, is generally concave (as viewed from the lamp housing) but may actually have become convex by the time it begins to leave the gate. The problem is by no means a simple one, from the standpoint either of picture projection or of sound-track scanning.—*JP*]

The General Precision magnetic soundhead, which is marketed under the name Simplex, is designed not to affect the normal operation of the projector when films with photo-

[1] All three are on the staff of the General Precision Laboratory, Inc., Pleasantville, New York. Their joint paper, "Four-Track Magnetic Sound Reproducer for Composite Films," was read by Mr. Athey and subsequently published in full in *J. Soc. Motion Picture Television Engrs.*, **62**, 221-227 (March, 1954).

graphic tracks are run on it. The latter can be threaded up to bypass the magnetic pickup system; films with CinemaScope-type sound tracks may be threaded in such a way as to bypass the optical sound-scanning system.

THE MECHANICAL FILTER SYSTEM

The magnetic soundhead is entirely film-driven and uses a "tight-loop" stabilizing system to promote uniform film motion. Damping for the filter system is provided by a rotary viscous damper employing a sector of a cylinder rotating in a silicone fluid inside a cylindrical drum. The natural period of the filter is claimed to be about one-third of a cycle; excellent flutter performance is said to result.

Because the single sprocket which is used acts "passively," the filter system is "well isolated from external disturbances" and exists in a "sort of back-water or eddy off to one side of the main film path."

Nonmagnetic material is used for all parts of the soundhead—except the four pickup heads per se, of course—which come in contact with the film's magnetic stripes.

THE MAGNETIC PICKUP AND ITS POSITIONAL ADJUSTMENTS

The pickup head is Brush type BK 1544-S1237, manufactured to Twentieth Century-Fox specifications. A Cannon-type DA-15P plug, mounted on one side of the head, and a mating plug and shielded harness carry the connections to a barrier terminal strip in the connection box on the front of the soundhead.

The pickup proper is mounted on a bracket which is held on a slide by a spring and a lockscrew. This slide permits lateral adjustment of the head relative to the film, and a stopscrew and locknut arrangement is provided to maintain correct positioning once achieved.

Three setscrews in the base of the magnetic head permit azimuth and tip adjustment of the head relative to the bracket. The three head-mounting screws lock this adjustment once it has been made.

An annealed Mumetal front shield may be removed readily for purposes of head cleaning and degaussing. In projection booths where severe hum fields exist, a box shield, which slips over the magnetic head and is held by spring tension, is provided.

The electronic equipment is housed in wall-mounting cases. The preamplifier case mounts four plug-in preamplifiers. The power supply-switcher case mounts one power supply and two "effects" switchers.

The electronic complement for a two-projector setup consists of a pair of preamplifier cases, mounting four preamplifiers for each projector, and one combination power supply-"effects" switcher case.

For a *three*-projector installation, an additional preamplifier case and an additional power supply case are used. Because, in this instance, the second power supply feeds only *four* instead of eight preamplifiers, a removable dummy load is incorporated. (This load is *not* a plug-in unit.)

Each preamplifier is of conventional design, employing a 5879 tube and a 12AT7 tube. The 5879 is connected as a pentode and is followed by an RC equalizing circuit. The 12AT7 is connected as a cascaded triode amplifier with feedback over two stages. A potentiometer in the feedback network provides gain adjustment of approximately 6 db. The output transformer is connected for 500-ohm output.

For purposes of gain measurement, the source impedance of each individual head comprising the quadruple-track pickup unit "is considered to be nominally 50 ohms," said Messrs. Athey, Borberg, and White. "The dummy source which is actually used for measurement consists of a 6-ohm generator in series with a magnetic pickup head. For calibration this source is terminated in 50 ohms, and the power into this resistor is considered to be the signal delivered to a nominal 50-ohm load.

"With the gain control set at maximum, the gain of the preamplifier at 1000 cps is 75 db." According to the authors, the output noise, at this setting and with the input short-circuited, is –45 dbm. "The output signal at 1000 cps, from a 50-mil track modulated to 3% distortion, is +7 dbm, and for a 29-mil track at 5% distortion, +1 dbm . . . the distortion rises to 1.2% at 50 cps. The recording pre-emphasis of 6.5 db at 50 cps, however, assures that the maximum level at 50 cps, for 3% recorded distortion on the film, plays back at +0.5 dbm at the preamplifier output. At this level, the output distortion of the preamplifier is less than 0.5%."

The power supply is conventional and unregulated, with a two-section, choke-input filter. Two separate dc filament supply units are provided as part of each power supply. Each dc unit lights the heaters of four preamplifiers and delivers 600 ma at 19 volts dc, using only "a single-condenser filter." Residual ripple is 0.5 volt peak-to-peak.

The heaters of the 5879 tube and the 12AT7 tube are connected in series, with the 12-volt connection used for the latter. Also provided is 6.3 volts ac for the "effects"-switcher filaments.

THE "EFFECTS" SWITCHERS

It is the function of the "effects" switchers to connect the outputs of the "effects"-track preamplifiers to the power amplifiers which drive the "audience-surround" loudspeakers whenever a 12-kc control tone appears on the effects track. When the tone is absent, the preamplifiers are electrically disconnected. This serves to remove distracting hiss, crackling noises, or crosstalk from the "audience-surround"

speakers when no 12-kc signal is present on the "effects" track.

Each switcher employs a tuned circuit to select the 12-kc control tone and apply it to the grid of one-half of a 12AT7 tube, which acts as a tuned amplifier for the 12-kc tone. After amplification, it is rectified and filtered by means of a voltage-doubler arrangement. The resulting direct current is then applied to the grid of the *other* half of the 12AT7 to control a plate-circuit relay which, in turn, controls the connection between the "effects"-track preamplifier and the "effects"-track power amplifier. An additional tuned circuit discriminates against the control tone in the sound path. The outputs of the "effects" switchers, incidentally, are connected in parallel.

According to the authors, the over-all system frequency response (from CinemaScope multifrequency test film) is flat within ±1 db between 40 and 12,000 cps. System distortion (total harmonic) is 0.75% at "3% recorded distortion level on test film." Using CinemaScope flutter test film, Messrs. Athey, Borberg, and White found less than 0.2% flutter "one-sided peak."

THE WESTREX "BUTTON-ON" CINEMASCOPE REPRODUCER

The Westrex Corp. was one of the companies requested to design a multichannel, top-mounting magnetic soundhead for CinemaScope-type release prints. The unit ultimately evolved was described by C. C. Davis and H. A. Manley.[2]

In the design of the required film-transport mechanism, it was felt that three factors required special attention, said Messrs. Davis and Manley.

FILM TRANSPORT DESIGN CONSIDERATIONS

The first of these factors was to secure successful scanning of the relatively narrow magnetic tracks. "The solution was found to be an optimum combination of film tension and angle of wrap about the heads"—a combination which produced "good head contact without excessive polygoning of the film." (Such polygoning tends to increase in the area adjacent to the sprocket holes as the angle of bend of the film is increased.)

The second problem was the "design of a mechanical filter mechanism with an exceedingly low natural period in order to discriminate against as many as possible of the external disturbances which may arise in the projector mechanism or in the upper film magazine."

The third factor arose from the small diameter imposed on the impedance drums and bearings by the space limitations. "This," explained Messrs. Davis and Manley "placed a severe requirement on the concentricity of these parts in order to avoid proportionately increased flutter at a 5.7-cps rate, to which the ear is quite sensitive." This particular difficulty was minimized "by making each drum and shaft from a single piece of stainless steel and employing a precision-ground finish."

The film-pulling mechanism ultimately evolved is similar to other magnetic film-pulling mechanisms using the Davis drive, with two impedance drums, except that here the dual-purpose large sprocket is *film*-driven, the film itself being driven by the upper sprocket in the picture projector.

"Threading is aided by holes through two targets on the filter arms which become concentric when the correct length of film" has been threaded. "The front surface of the rear target is painted red, adjacent to the target," said the authors, "so that the red shows through the hole when an incorrect length of film is threaded."

[The present writer always applauds whenever designers and manufacturers of projection equipment incorporate simple, foolproof arrangements that tend to guard the operator against threading up an incorrect length of loop. These loops are indispensable in present-day intermittent projectors, because the film moves past the picture aperture *not* at a continuous rate but in a series of jerks or "pull-downs." As the film travels from the picture aperture to the sound-scanning point in a conventional projector, the intermittent motion of the film is translated into smooth, continuous motion. With CinemaScope-type release prints, the film is moving at a continuous rate at the point where the magnetic stripes are scanned. The existence of the loop permits this continuous motion to be translated into intermittent motion at the picture gate, which should be 28 frames ahead physically of the sound-scanning point. To keep picture and sound synchronized, the loop between the picture gate and the sound-scanning point must be adjusted to the proper length. Incidentally, one of the perpetual hazards faced by producers who put lip sync sequences into films that will ultimately be run on 16-mm sound projectors by inexperienced operators is that the loop between the picture gate and the sound drum will, as likely as not, be made too short or too long. The neophyte invariably blames the producer when the lips and the voice, so carefully kept in sync during editing and assembly, prove to be out of step during projection.—*JP*]

Mechanical arrangements are provided in the Westrex soundhead to "prevent film breakage should the operator fail to close the pad arms before starting the motor." To avoid abrasion of either film base or emulsion surface, "all film-contacting surfaces have been undercut in the picture area." The rotating elements in the filter system are ball-bearing mounted, except for the sprocket, "which has a specially lubricated Oilite bearing."

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[2] Both of the Westrex Corp., Hollywood, California. The paper was presented on behalf of the authors by John G. Frayne, also of Westrex. The full version appeared subsequently in *J. Soc. Motion Picture Television Engrs.*, **62**, 208-214 (March, 1954).

THE QUADRUPLE-HEAD PICKUP UNIT

The magnetic pickup assembly consists of three 50-mil heads and one 38-mil head "located on a common axis and mounted on a base plate." Positioning of the individual heads comprising the pickup is fixed at the time of assembly in accordance with the CinemaScope proposed standards for magnetic sound reproducing equipment. "The heads are shielded against stray magnetic fields by a Mumetal case and shield."

The four heads of the pickup contact the magnetic stripes on the film at a point midway between the two drums, thus making symmetry of film wrap about each gap independent of variations in film compliance.

Means are provided, said Messrs. Davis and Manley, for adjusting the heads *as a unit* to insure correct azimuth, gap centering, and track position.

The amplifier assembly consists of four preamplifiers mounted in a metal box. "It has been designed to provide a signal output from the four magnetic heads at a nominal level of –12 dbm for the stereophonic tracks proper and –18 dbm for the 'effects' track."

The innate frequency-response characteristic of the amplifiers, according to Messrs. Davis and Manley, plus the response characteristic resulting from scanning with heads having 0.5-mil gaps, yields "an over-all reproducing characteristic which is in accordance with the standard proposed by the Motion Picture Research Council. The resulting over-all frequency characteristic is flat from 50 to 8000 cps within the limits of the proposed standard."

When the Westrex magnetic reproducer is mounted on top of a projector in "good operating condition," the low-frequency flutter components, claimed the authors, "are not greater than 0.03% while the total root-mean-square value of flutter is within the 0.15% value which is the generally accepted requirement for theater equipment."

The authors claimed further that "the guiding of the film at the sprocket reduces film-weave to a minimum." This, obviously, is highly desirable, in view of the narrowness of the four magnetic stripes carried on each CinemaScope release print.

[The importance of holding film weave down to a minimum will be appreciated when it is considered that in a quarter-inch tape recorder using full-track heads the nominal width of the sound record is 250 mils. Where half-track heads are used, the track width is 125 mils. The "button-on" magnetic soundheads for CinemaScope, on the other hand, must accurately scan four narrow stripes—three of them 63 mils wide (in the proposed standard). These are scanned with 50-mil heads. The fourth, or "effects," track is 29 mils wide and is scanned with a 38-mil head. In short, three of the tracks are about one-quarter the width of a standard quarter-inch full-track tape recording, and one track is less than one-eighth the width of a full-track tape recording. It should be borne in mind, too, that present-day photographic film is a stiffer and far less compliant medium than quarter-inch tape; it has a total thickness of about 6 mils—approximately four times that of quarter-inch tape.—*JP*]

THE RCA "TOP-MOUNTING" FOUR-TRACK REPRODUCER

The RCA magnetic soundhead was described by J. D. Phyfe and C. E. Hittle.[3] This, too, is a "film-pulled" unit.

Experience has proved, said Messrs. Phyfe and Hittle, that vibration of the magnitude which may be present in the majority of present-day motion-picture projectors can adversely affect the film motion at the magnetic scanning point, giving rise to excessive high-frequency flutter. For this reason, the mechanism panel assembly of the soundhead is supported inside the housing by means of four rubber isolation mounts "with adequate clearance being provided between the edges of the panel and the interior of the housing to eliminate any metal-to-metal contact between the panel and housing."

The upper sprocket is driven from the lower sprocket by means of pulleys of the timing-belt type, mounted on the rear of the sprocket shafts, and a connecting precision-molded, tooth-type rubber belt. This type of drive, declared Messrs. Phyfe and Hittle, gives results comparable to those which would be obtained with a precision gear drive and at considerably lower cost. Both sprockets are of the 16-tooth type, with tooth width and tooth pitch selected specifically for the new type of perforations used with CinemaScope release film.

The filter system is a film-pulled, drum-type, "soft-loop" system. The drum-shaft assembly includes a solid flywheel mounted on the rear of the drum shaft. Most of the random irregularities in film motion occurring on the *feed* side of the soundhead, said the authors, are absorbed in the compliance loop *ahead* of the drum.

Tests were made, according to Messrs. Phyfe and Hittle, on models utilizing both "tight-loop" and "soft-loop" filter systems; film motion was comparable on the two systems when either was used with a projector having good feed-sprocket motion and a feed magazine producing uniform drag or holdback. "However, when projector feed-sprocket motion and feed-magazine drag were not uniform, a condition likely to be encountered in the field, film motion obtained with the 'soft-loop' filter system was superior to that obtained with the 'tight-loop' system."

The four individual magnetic heads of the pickup unit proper are contained within a single, precision-cast housing.

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[3] Both of the RCA-Victor Division, RCA, the former at Camden, New Jersey, the latter at Hollywood, California. Mr. Phyfe read the paper, which was subsequently published in full in *J. Soc. Motion Picture Television Engrs.*, **62**, 215-220 (March, 1954).

"The face of each half-cluster is lapped on a precision flat. . ." This procedure puts "all the gaps in true alignment when the half-clusters are assembled together." During assembly, azimuth, head height, and track location are accurately adjusted with respect to the mounting surface. After assembly and final lapping operations, heads are inspected for conformity to design specifications with respect to azimuth, head position, inductance, and uniformity of output.

The head assembly is mounted in the soundhead adjacent to the drum so that the magnetic stripes on the film contact the respective heads immediately after the film leaves the drum. The aim was to locate the head at that point in the film path "where best film motion exists."

The angle of contact of the film on the pickup head is approximately 30 degrees. "This degree of contact assures minimum amplitude modulation and is beneficial in prolonging useful head life," said Messrs. Phyfe and Hittle.

Flutter content of less than 0.15% rms was found when measured with a test film having an inherent flutter content of less than 0.1% rms. Amplitude modulation was less than 1 db. Uniformity of output within 1½ db at 8000 cps and 1 db at 1000 cps was claimed.

Because the various projectors currently in use vary considerably with respect to size and configuration of the top surface, it was considered impractical to design the soundhead for *universal* mounting. Instead, the unit was engineered for mounting on a projector having a flat top surface of "adequate area"; adapters have been designed and are promised to permit mounting the soundhead on the various other projectors now in use.

THE AMPEX FOUR-CHANNEL REPRODUCER

The unit developed by Ampex for the Magna Theatres Corp. was described during the week following the SMPTE Convention in a paper delivered before the Fifth Annual Convention of the Audio Engineering Society (October 14-17, 1953) by Walter T. Selsted.[4] Mr. Selsted's paper will not be summarized here as it has already been published in full in this Journal.[5]

Discussion—Equipment for Stereophonic Reproduction

The presentation of the foregoing papers was followed by an extended and lively extemporaneous discussion[6] from the floor, with John K. Hilliard, of the Altec Lansing Corp.,[7] as moderator. Dealt with were the general matter of equipment for stereophonic reproduction in the theater, the mechanical problems involved in transporting CinemaScope-type film, the relation of sprocket-tooth size to flutter, the new "Fox-hole" perforations versus the "old" standard perforations, equalization problems and philosophies, and the like. Discussions of this type, where technical people can think out loud and the emphasis is on the airing of opposing viewpoints, are all too rare.

Arthur C. Downes, Chairman of the Board of Editors of the SMPTE, William H. Rivers, Chairman of the Papers Committee of the SMPTE, and Victor Allen, Editor of the SMPTE Journal, are to be commended on their general policy of publishing such discussions in almost verbatim form.

Below, in very much condensed form, are selected items from the discussion. The material has been reorganized considerably, and explanatory notes and background material have been added to render the subject matter more meaningful and intelligible to those audio people whose chief personal interests may not necessarily lie in the field of motion-picture audio.

TENSION OF THE FILM OVER THE MAGNETIC HEAD

E. K. Carver, of the Eastman Kodak Co., asked what order of film tension was required over the quadruple-head magnetic pickup, especially in the two "button-on"-type reproducers "where a combination sprocket is used" [i.e., the Westrex and the General Precision Laboratory units; the RCA version uses a *pair* of individual sprockets.—*JP*]

"It's approximately 400 grams in the closed film loop," replied Dr. Frayne.

Mr. Athey thought "the actual tension in the film is of the order of 8 ounces and the force against the head is of the order of 3 or 4 ounces."

QUADRUPLE-TRACK HEAD ADJUSTMENT AND CONTACT PROBLEMS

George Lewin, of the Signal Corps Pictorial Center, wanted to know whether the multiple-headed magnetic pickups incorporated arrangements so that separate, individual adjustments could be made on each one of the four magnetic heads, with respect to head-to-stripe contact.

"With the Brush head, which we are presently using," replied Mr. Athey, "there is no way in which the individual contact can be adjusted other than that the entire head can be tipped." Later on Mr. Athey added, "The present head is potted in plastic. It would be something of a problem," he pointed out, to adjust the position of, say, the second magnetic head with respect to that of the first and third

[4] Ampex Electric Corporation, Redwood City, California.

[5] "Multichannel Sound Reproduction," *J. Audio Eng. Soc.*, **2**, 20-24 (January, 1954).

[6] Subsequently published under the title "Equipment for Stereophonic Reproduction—Panel Discussion," *J. Soc. Motion Picture Television Engrs.*, **62**, 228-238 (March, 1954).

[7] Beverly Hills, California.

heads. "Our knowledge of the effect of lack of individual track adjustment as it affects the life of multiple-track composite film is, I'm afraid," he said, "rather elementary." He suggested that such provision for individual head adjustment might ultimately become desirable to take care of any possible differential wearing of the four individual magnetic heads comprising each pickup. "At the present time, the attitude that we have taken (and, I believe, the other manufacturers, too) is that if the filter system is properly aligned, so that the tension is equalized between the two sides [edges—*JP*] of the film and the contact surface of the head is flat, then, for all practical purposes, the tension and the head contact are constant across the film."

THE RELATIVE IMPORTANCE OF HEAD CONTACT DURING RECORDING AND REPRODUCING

Mr. Lewin assumed that "the adjustment for reproduction must be a lot less critical than for recording" and stated further that "we probably would miss terrifically the absence of an individual adjustment for each head, since I don't think the film ever lies completely flat."

Mr. Athey agreed that poor contact could be more serious during recording "because of loss of bias and the like" than during playback. It was apparently easier, he ventured, to make the magnetically striped film stock lie flat over a contact area 50 mils wide [the reference here was to scanning width of an individual magnetic playback head—*JP*] than to maintain good head-to-stripe contact across a 200-mil or a 250-mil head "at part of which the contact may be poor." [Tracks 200 or 250 mils wide are by no means uncommon in production recording on magnetically coated film.—*JP*] In Mr. Athey's opinion, "the localized tension in the narrow track eliminates many of the difficulties that may occur with wider tracks, where the film is relatively stiffer."

Mr. Lewin wanted to know whether the CinemaScope-type film would lie flat enough so that, if good contact were secured with *one* head, there would be good contact on the other heads, "especially the ones in the middle." Mr. Lewin suspected that, if the head contact were good for the two *outside* magnetic tracks, "the track inside—the one that's in the conventional sound-track position—might tend to dish inward" and make poor contact.

"We do not have any proper evidence," said Mr. Athey, "but it is my impression that the situation is exactly backwards. . ."

Dr. Frayne brought up the matter of "film with a 'Toni' in it." (The Eastman Kodak Co. defines this as fluting or waviness along the edge of the film, usually on one edge only but sometimes along *both* edges.) His company's only problem, he said, had been with film in that particular condition. "If you get a film with a bad 'Toni' in it," said Dr. Frayne, "then, of course, you get very bad contact, but if the film is in normal condition, then there's no particular problem."

HIGH-FREQUENCY FLUTTER IN MAGNETIC FILM SYSTEMS

John A. Maurer, of J. A. Maurer, Inc., inquired whether anyone on the Panel had information on the frequency spectrum of the flutter which occurs in magnetic film systems. Mr. Maurer also wanted to know why it was "so hard to get the flutter in the recording below 0.1%."

Dr. Frayne recalled previous papers of his own in which he had indicated that it had not yet been possible to reduce the high-frequency flutter content in magnetic film recording to as low a value as in photographic systems.

"If you remember the old straight gates in photographic [sound] recording in 1928, they were not very good, either," said Dr. Frayne. "When we went to drum scanning, we had no frictional contact and we succeeded in getting excellent flutter performance on photographic film."

Dr. Frayne stated that the greater value of high-frequency flutter content which characterizes magnetic film recordings today is "not entirely harmful, because the flutter rates are very high. On a typical flutter chart on magnetic you'll get excellent flutter performance until you get up in the 96-cycle region and then you may find values of the order of 0.10% and 0.15%. On a very good job it may be as low as 0.05%. [The number "96" has always been significant in 35-mm sound-on-film recording because that is the number of sprocket holes that are "pulled down" every second, i.e., 24 frames per second multiplied by four sprocket holes to the frame (on either side of the film band). Much work has been done in the motion-picture field to eliminate or minimize 96-cycle disturbances.—*JP*] Then, in the band, say, between 100 cps and 200 cps, the flutter may jump some more. In general, I would say that magnetic recording is inferior to photographic [recording] in the high-frequency flutter rates," he concluded.

Mr. Maurer asked if the real trouble might not be "longitudinal vibration of the film past the head." Dr. Frayne replied that it appeared to be so.

HIGH-FREQUENCY FLUTTER AND TELEMETERING

Edward Schmidt, of the Reeves Soundcraft Corp., Springdale, Connecticut, pointed out that the problem of high-frequency flutter affected not only magnetic film recording in the motion-picture industry but other applications as well, like telemetering in connection with FM work. Mr. Schmidt stated that considerable work was being done "by all manufacturers of magnetic products to reduce or cut down on the head-scrape." This term, he suggested, was the "best term that we've come upon so far" for this phenomenon. He implied that it might best be described as the coefficient

of friction between the coating and the magnetic head.

Dr. Frayne remarked that apparently "some manufacturers put out what they call a lubricated magnetic coating which does improve the high-frequency flutter performance."

[It should be noted, in this connection, that motion-picture release prints are often lubricated with a very thin layer of a wax like Carnauba. The latter is applied by running the new print through a bath made up by dissolving a small amount of the wax in a relatively large volume of carbon tetrachloride.—*JP*]

THE RELATION OF SPROCKET FORM TO FLUTTER

Referring to the work done at General Precision in evolving a top-mounting reproducer for quadruple-stripe film, Mr. Athey said, "In the early development [work] we did not have sprockets of the proper pitch and our flutter performance was therefore not very good. However, with sprockets of optimum pitch diameter, flutter due to the ripple is essentially eliminated over a normal range of film shrinkage." [The allusion here was to "*tooth* ripple," as it has been called. Since 96 perforations are successively engaged by the sprocket teeth every second, the frequency of "tooth ripple" would be just that—96 cps.—*JP*]

Earlier Mr. Athey had commented that the "sprocket form is of crucial importance." At the General Precision Laboratory, he added, they prefer to avoid the use of a "full-fitting tooth . . . because the reproducing equipment must operate properly with shrunk film, as opposed to the essentially unshrunk film with which recording equipment operates."

DIMENSIONS OF THE SPROCKET-TOOTH BASE AND THE "CROSSOVER" EFFECT

According to Dr. Frayne, in Westrex's "Davis Drive, we have always recommended a sprocket-tooth base that nearly fills the sprocket hole in the film. This minimizes the 'crossover' effect [at any point] where the tension in the filtered film exceeds or becomes less than that in the external film paths. This 'crossover' [effect] usually results in high flutter content at this point in the film running. In the Westrex CinemaScope head we use a tooth base dimension of 70 mils. We would like to use a base of 73 mils and completely fill the sprocket hole," said Dr. Frayne, but the fact that film shrinks cannot be disregarded, he implied.

"The most prevalent causes of the 'crossover' trouble," declared Mr. Athey, "are bent reel flanges, nonuniform friction of the feed-spindle brake, and sticky fire-valve rollers [in the projector]. With properly adjusted equipment," added Mr. Athey, "the 'crossover' phenomenon can be prevented throughout the run of the reel, and flutter from this source can be eliminated."

SPROCKET DIAMETER AND FILM LIFE

According to Dr. Carver, "we found that the increase in the diameter of the sprocket, leading to an increase in pitch and to a correct sprocket-tooth film-pitch relationship, increased the life of the film a very great deal." With the magnetic stripe left off the film (thereby avoiding the significant increase in friction occasioned by the presence of the stripe), film life was increased by almost a factor of 10 compared with the life of film run over the *older* type of sprocket.

Replying to a question from Loren L. Ryder, of Paramount Pictures Corp., Dr. Carver said, "I think that the old sprocket hole [perforation] runs a little better with *all* sprocket teeth than the smaller sprocket hole [i.e., the CinemaScope-type perforation—*JP*] . . . What I'm saying really is that if you have the right size [diameter of] sprocket, you're way ahead of where you've been in the past, anyhow. The small amount that the smaller sprocket hole takes away from your [film] life is a very small fraction of what you gain by the increased size sprocket."

FILM WEAVE AND THE LATERAL GUIDES IN THE PROJECTOR

In reply to a question concerning how well 35-mm film possessing the present standard perforations would ride on the new, narrower CinemaScope-type sprocket tooth, Ralph Heacock, of the RCA-Victor Division, RCA, Camden, New Jersey, expressed the view that the pair of lateral guides located in the film trap, one on either side of the film, "are the determining factor for lateral weave." Even though the CinemaScope sprocket tooth is narrower than the conventional tooth, said Mr. Heacock, the lateral guides (also called "studio guides" by Mr. Heacock) "will still be the determining factor in lateral weave." He pointed out that at least one of the two lateral guides is adjustable; ". . . . you adjust this guide to give you the steadiest picture possible, taking into account the variation due to shrinkage in the width of the film."

Mauro Zambuto, of Italian Films Export, commented, "Most of the time, when a splice goes by, you find the lateral guide fails to be the determining factor."

Mr. Heacock conceded that at such moments conditions might be quite unusual but insisted that under *ordinary* circumstances—regardless of whether the old standard width of tooth or the new narrow tooth were used—the lateral guides would still be the determining factor as far as weave was concerned.

"EFFECTS" TRACK SWITCHING

The present CinemaScope playback system [the system in use in October, 1953—*JP*] is set up in such a way that the 12-kc control signal is present when "effects" are to be reproduced. That is the way *The Robe* was recorded.

Dr. Frayne had proposed, apparently, that "succeeding pictures should be recorded differently," i.e., with the 12-kc control signal present when it was desired to turn the "effects" track *off*. The change, said Dr. Frayne, "was a very simple change to make in the field."

Mr. Athey felt that to maintain the 12-kc control signal while the "effects" track is on ". . . is certainly, in one sense, the hard way to do it. It is my impression from the demonstration recordings that we made for Fox," he continued, "that the modulation noise from the 12 kc, even though the 12 kc is not audible, is a disturbing factor. Unfortunately, and this is just my guess from not very exact results, as the frequency gets higher, any errors in recording contact become more impressive in their effect on the signal."

The result of imperfect contact, said Mr. Athey, is that the modulation noise *itself* becomes modulated. He conceded, however, that the presently accepted approach, namely, that of having the 12-kc control signal *on* to open up the "effects" channel and *keep* it open, offered the advantage of system simplicity.

It had been suggested, he added, that perhaps the 12-kc control signal could be used to turn on the left-hand speakers, that a 14-kc signal could turn on the middle speakers, and that the "*lack* of a control signal would turn on the right-[hand] speakers and something like 13 kc would make the whole system dead."

No decision had been made on suggestions of this type, nor had any recommendations been offered, said Mr. Athey, concerning the use of a control signal markedly higher in frequency than 12 kc.

[Of interest in this connection is Perspecta Sound, which was demonstrated by C. Robert Fine and his staff before a meeting of the Atlantic Coast Section of the Society of Motion Picture and Television Engineers this month (April, 1954). Perspecta Sound is a system whereby a simulated stereophonic playback is derived from a *single* photographic sound track by assigning to each of the three loudspeaker systems located behind the screen the desired level for each. The individual levels are varied, but beyond that no transmission change is effected in the signal secured from the single photographic track. In addition to the program material per se, control information at three different frequencies is laid down on the single photographic track—at 30 cps, 35 cps, and 40 cps. These frequencies were chosen, Mr. Fine explained, because motion picture photoelectric playback systems are very efficient at the lower end of the audio spectrum and because rarely is any program material which appears in this region of a sustained character, unvarying in amplitude. Thirty cycles per second turns on the *left*-hand channel of the three-channel system, 35 cps turns on the *center* channel, and 40 cps serves to turn on the *right*-hand channel. The details of the Perspecta Sound system are described in a paper which will appear in due course in the *Journal of the Society of Motion Picture and Television Engineers*. The matter will be reported in the *Journal of the Audio Engineering Society.—JP*]

LACQUER COATING OF MAGNETIC STRIPES

E. S. Carpenter, of Escar Motion Pictures, Cleveland, Ohio, inquired whether any experiments had been conducted in the matter of "lacquer coating the film or the sound stripe."

Mr. Edward Schmidt, of the Reeves Soundcraft Corp., Springdale, Connecticut, doubted that "any normal lacquer coating over the sound track would be useful in any respect. "Magnetic recording depends on intimate head contact for optimum results," he said. Anything you lay down on top of the magnetic stripe, he indicated, will interfere with contact. The tolerance with respect to head-to-stripe contact, declared Mr. Schmidt, is "zero."

THE AMPEX PROPOSAL—MORE HIGH-FREQUENCY BOOST

Walter T. Selsted contributed the following statement, which was read in his absence by Charles H. Wirth, of the New York office of Ampex:

"As most of you know, the Ampex Corp. has recently developed studio and field recording equipment for the Magna Theatre Corp.," said Mr. Selsted's statement. "Recently we have developed a complete line of theater sound reproducing equipment designed specifically for the reproduction of CinemaScope pictures.

"During our work on these projects, we made extensive investigation of the relationship which pre-emphasis and post-emphasis bear . . . to weighted signal-to-noise ratio and distortion. The pre-emphasis and post-emphasis characteristics established through the NARTB [the National Association of Radio and Television Broadcasters] were based on studies made relating sound-source energy distribution with saturation characteristics of magnetic recording media. The studies of energy distribution made by the Bell Telephone Laboratories in 1929 were recently repeated by the Ampex Corp., which found excellent agreement. Recently repeated tests confirm that the NARTB standard characteristics are an optimum compromise between unweighted signal-to-noise ratio and high-frequency tape saturation. Great improvement can be realized in the listening quality of narrow-track magnetic recordings now being introduced for motion-picture sound, if the record pre- and post-emphasis at high frequencies are reconsidered, placing more importance on weighted signal-to-noise ratio and putting less importance on occasional high-frequency compression due to magnetic saturation. In design of the equipment for the Magna Theatre Corp., we appreciably altered the pre-emphasis characteristics in the recorder with a resultant improvement

in weighted signal-to-noise ratio of better than 10 db. Recently, studies we have made indicate that, using similar techniques and suitably choosing the recording material, an improvement of approximately 16 db can be achieved on a weighted basis. These improvements in signal-to-noise ratio are primarily in the upper end of the audio spectrum where tube and tape hiss are the objectionable quality of which the listener is immediately conscious. The techniques we have used indicate an improvement of at least 7 db throughout the rest of the spectrum."

According to Mr. Wirth, "Ampex has had such good results" with the above-described equalization "that we would like, at this time, to propose that the Ampex equalization characteristic be accepted as an industry standard as well as . . . adopted by the Society of Motion Picture and Television Engineers."

With a pair of lantern slides Mr. Wirth compared the present recording and playback characteristics with those proposed by Ampex.[8] With respect to the two curves comparing the present and the proposed high-frequency equalization characteristics, Mr. Wirth remarked that the 6-db spread between the two at the low-frequency end "merely illustrates the approximate increase in output from the tape realizable by means of the new oxide developed by Minnesota Mining."

Mr. Wirth then called attention to the curves showing "the necessary playback equalization to complement the record characteristics in each of the two former cases. As you will notice," he said, "the spread between the two curves [i.e., the reproducing characteristics] beyond 1000 cps increases materially. Since it is in this region where the most audible hiss occurs, the improvement in signal-to-noise ratio at any particular frequency is approximately equal to the spread between these two curves."

PROS AND CONS

Loren L. Ryder, of the Paramount Pictures Corp., announced that he was on the side of Ampex. At Paramount, he explained, they had been using between 10 and 12 db of pre-emphasis at 8000 cps all along in magnetic recording. "We have good success recording that way and, I should say, far less trouble than in other recording activity. At Ryder Services [Mr. Ryder's own plant—*JP*] when I do outside work, I comply with the standard of the industry . . ." [i.e., he uses the *customary* amount of high-frequency boost, which is significantly less than the amount recommended by Ampex.—*JP*] Mr. Ryder stated that he prefers the added high-frequency pre-emphasis, claiming further that, if "there is varying contact in recording and reproduction, the effect is not as bothersome" when he uses the extra high-frequency boost as when he does not. He made it very plain that he is in favor not only of increased high-frequency *boost* in *recording* but also of more high-frequency *droop* during playback, "especially as we diminish the width of the sound track."

Dr. Frayne offered the comment that, since his own company had "supplied some equipment to Paramount studios, I can elaborate a little on Mr. Ryder's remarks. I'm quite sure that Mr. Ryder continued to use the same pre- and post-equalization on magnetic [recording] that Paramount had used on photographic recording. . ." Equipment for the latter type of track had been supplied to Paramount by Westrex, Dr. Frayne indicated. The equalization used in it, he said, "is not nearly as drastic as Ampex proposes. It flattens off, as a matter of fact, around 6500 cps and, at least as originally supplied, it does not exceed 12 db. Now, also bear in mind that the experience at Paramount is with *original* recording," continued Dr. Frayne, rather than with release prints. [The sound track on a release print, whether it is a photographic track or a magnetic track, can be anywhere from five to ten—or more—"generations" removed from the *original* recording that was made during *production*. The various losses that occur during successive re-recording and processing steps generally tend to be *cumulative*.—*JP*] As far as he knew, Dr. Frayne observed, Paramount had not released any films embodying the degree of high-frequency boost proposed by Ampex to the theaters, "because the theaters couldn't play it back."

NARROW STRIPES vs WIDE STRIPES

Dr. Frayne then pointed out that the Motion Picture Research Council had suggested no more than about 3 or 4 db of pre-emphasis at 8000 cycles. Later, he reminded his audience that 200-mil tracks, such as were used in the first magnetic installations for theater reproduction at the Chinese Theatre in Hollywood [and such as are not infrequently used in original recording on the Coast—*JP*] have an advantage over 50-mil track.

A bit further along, Mr. Wirth declared that, in his opinion, "the whole key to this discussion" was that "we are now dealing with very narrow-track magnetic stripes." With reference to noise, Mr. Wirth stated that "with [the repeated] re-playing of CinemaScope films, no doubt, we will be able to get some quantitative information as to deterioration of signal-to-noise ratio due to the rubbing off of the oxide and other effects."

Another thought that Mr. Wirth threw into the hopper was: ". . . I think that the concept of using high-frequency pre-emphasis to compensate for inefficiencies in head design or defects thereof is one of the evils of the magnetic recording industry."

[8] The identical curves accompany Walter T. Selsted's paper, "Multichannel Sound Reproduction," *J. Audio Eng. Soc.*, **2**, 20-24 (January, 1954). The curves appear on pp. 23 and 24, respectively.

Mr. Athey subsequently asked Mr. Wirth whether the equalization proposed by Ampex was for a "half-mil playback gap. Since *our* system [i.e., the General Precision "top-hat" reproducer] is designed for the half-mil gap," said Mr. Athey, "we wouldn't like to go to a larger gap." Mr. Wirth replied that the Ampex equalization curve was for a "*quarter*-mil gap."

THE DANGER OF OVERLOAD AT THE HIGH END

"This problem has been considered at great length for several years," said Mr. Hilliard, "both from a radio-channel and recording-studio standpoint. The NARTB curve referred to 16 db of pre-equalization. . . ." Mr. Hilliard thought that "the amount of equalization proposed [by Ampex] is as drastic as was used in the NARTB curve." The trend has gradually been *away* from such pronounced high-frequency boost, said Mr. Hilliard. ". . . I know from experience in motion-picture sound that this amount of equalization [i.e., the marked high-frequency boost proposed by Ampex—*JP*] was tried originally and has been dropped because of the fact that you would penalize yourself in overall level or overload or a combination of both."

Mr. Hilliard cited the test reel of the Research Council of the Academy of Motion Picture Arts and Sciences. In examining the frequency content of this test reel, said Mr. Hilliard, "it was found that the 100% modulation point in speech was repeated more often in the range between 2000 [cps] and 6000 [cps] than in any other region." From this he concluded that "it behooves us to approach the degree of equalization that is proposed in a very cautious manner, because of the nearness of the microphone in the case of recording. . . ." [This, apparently, was a reference to the fact that the "close-talking," low-volume technique which is so often used in radio broadcasting and is by no means unknown in film recording tends to accentuate the high-frequency content as well as the low-frequency content of voices.—*JP*] Mr. Hilliard was concerned, too, about sound effects and similar phenomena which may exhibit a significant amount of high-frequency content to begin with. The recording of this type of sound might pose problems, he implied, were the marked degree of high-frequency pre-emphasis advocated by Ampex to be adopted.

ACCENTUATION OF POSSIBLE HIGH-FREQUENCY HETERODYNES BY EQUALIZATION

Mr. Lewin suggested that increasing the amount of high-frequency boost used in magnetic recording might accentuate any possible heterodynes set up between the frequencies at the upper end of the audio spectrum thus boosted and the bias frequency. "I've noticed in making distortion measurements on magnetic recordings that when you get up into the high frequencies, you often get distortions that don't seem to show up on the meters, but your ear tells you" that they are present. Mr. Lewin thought that these distortion effects might be due to the aforementioned heterodynes or possibly something else. Whatever the cause, Mr. Lewin felt that "you have to be very cautious about increasing the amount of high-frequency boost in your recording, because even though the frequency response might look as though you had made an improvement and noise measurements might tell you" that you were getting less noise, the result might still be a poor recording, because it just wouldn't "sound clean on the high frequencies due to this heterodyning effect."

EQUALIZATION AND THE RELATIVE DISTRIBUTION OF ENERGY IN ENGLISH AND ITALIAN

Mr. Zambuto spoke of equalization in terms of the relative spectral distribution of energy in speech in different languages and the effect of the frequency-distribution pattern on signal-to-noise ratio. The middle-frequency content of *Italian* speech has been shown experimentally to be relatively greater than that of *English* speech, he said. "Therefore, it is often the experience of Italian mixers," said Mr. Zambuto, that if the region between approximately 2500 to 4500 cps is boosted, "you have to pull down your average level in order not to overmodulate and therefore you reach 100% modulation at a lower power level. As a result, you lower your expected signal-to-noise ratio considerably. I think this effect should be kept in mind," he added, "in evaluating . . . a new standard."

LOW-FREQUENCY EQUALIZATION

Mr. Athey brought up the matter of low-frequency pre-emphasis and pointed out that "we take advantage of it in order to reduce some of the requirements on our amplifiers. . . . We have a perfectly fantastic hum problem. [Mr. Athey was evidently referring to quadruple-track magnetic pickup equipment.—*JP*] I have made some very crude calculations here, and I believe that for a 50-db signal-to-noise ratio the hum signal must be less than –144 dbm at the input of the preamplifier. . . I therefore hope that we do not give up more than a db or so of the present low-frequency pre-emphasis."

MAGNETIC "PRINTER"

Dr. Frayne explained how the release prints for *The Robe*, the first commercial CinemaScope release, were "dubbed."

"We were asked by Twentieth Century-Fox to develop what was called a magnetic 'printer,'" said Dr. Frayne. The device consists of a master four-track reproducer which scans four master magnetic tracks each 150 mils wide and recorded on fully-coated film. It was necessary to design

a special four-track head for this machine, Dr. Frayne indicated.

The reproducer incorporates equalization "so that we get a 1:1 transfer as far as frequency characteristic is concerned. Then the output from this reproducer is fed to a battery of five quadruple-track recorders . . . " The latter can be mounted either in "cabinet-type racks or in a special cabinet which contains complete recording and reproducing transmission facilities."

The idea of speeding up the sound "printer" by running the film at a speed higher than the 90 feet per minute which is standard in 35-mm practice was considered but, because of the desirability of permitting the operator to monitor any one individual track on any one of the five different quadruple-head reproducers at will, "it was decided to retain the normal speed of 90 feet per minute."

The five reproducers, said Dr. Frayne, "are tied together in interlock, using a composite synchronous interlock type of motor which does not require any distributor." Any one of the five recorders "can be run individually for test purposes on the sync motor basis or any group of machines can be tied together by simply throwing a switch on each machine" to cause it to run in interlock.

The present release prints for *The Robe,* reported Dr. Frayne, "are being made with 50-mil tracks. . . ." The five quadruple-head recorders will ultimately be equipped with 60-mil heads to lay down a 60-mil track. "Obviously, from the weave standpoint," said Dr. Frayne, "it's desirable to have the recorder track wider than the scanning head in reproduction." The sound "printing" operation, Dr. Frayne concluded, was definitely *not* a bottleneck.

Magnetic Sound Subcommittee Report

[This particular material leans heavily on the mimeographed report of Henry Kogel, SMPTE Staff Engineer, dated October 23, 1953, which was mailed to all who had attended the Subcommittee's meeting, including the present writer. The information is summarized below by permission of Mr. Kogel.—*JP*]

The SMPTE'S Magnetic Sound Subcommittee, chaired by G. L. Dimmick, of RCA, heard reports on the status of various standardization efforts, including the following:

Reproduce Characteristics of 16-Mm Magnetic Sound Projectors. The question of how much equalization should be used and whether it ought to be "split equalization" (i.e., applied partly during recording and partly during reproduction) had yet to be resolved. Work was reported under way to secure agreement.

16-Mm Magnetic Test Films. Full-width, coated, azimuth-alignment films with a 200-mil record have been produced and sold since June, 1953. Considerable difficulty had been experienced in locating magnetic recording equipment suitable for the making of frequency films. Ultimately RCA had agreed to make ten films in New York. In the absence of calibrating equipment, it was agreed that each purchaser be furnished with a record of the recording-head current and a copy of the recording characteristic used in making the test film.

"Half-and-Half" Photographic and Magnetic Tracks. It was agreed to circulate the 53-mil proposal (SMPTE 635) to the Subcommittee for formal letter ballot.

Magnetic Coating of 16-Mm Film "Perforated Two Edges." A proposal was reported to be under consideration by the Sound Committee in this matter.

Among other things, agreement had yet to be reached concerning the permissible tolerance, between one make of machine and another, in the positioning of the magnetic scanning point with respect to distance, in frames, from the picture aperture. [The purpose, apparently, was to make it possible for a film recorded on *one* manufacturer's magnetic projector to play in *synchronism* on *another* manufacturer's machine. The question is almost academic today. Sixteen-millimeter magnetic projectors are generally used today by people who have shot a film silent, would like to put a sound track on it—of the post-narrated type—and need only a few copies, in most instances only a single copy. A reversal copy is usually made from the picture original. The copy is then sent out for striping, and the recording is laid down on the stripe, using as the magnetic recorder the self-same projector which will subsequently be used for playback. Some members of the Subcommittee, it seems, had been looking ahead to the day when interchangeability would be an important desideratum.—*JP*] Another proposal urged a tolerance of $\pm\frac{1}{2}$ frame. The Subcommittee felt that this proposal was not practicable because normally a projector is not threaded that accurately. [This, alas, is true, as producers of films for the 16-mm market have found to their dismay.—*JP*] It was agreed to table the matter until formally returned to the Subcommittee for consideration.

Magnetic Coating on 8-Mm Motion-Picture Film. A recommendation for a 52-frame separation between picture and sound had apparently been incorporated into an existing proposal. The question of whether to add a design tolerance with respect to the physical separation of the picture aperture and the sound-scanning point in different makes of machines had arisen but was dropped on the grounds that only a single manufacturer of 8-mm projectors was presently concerned with the question and because no definite proposal had been made to add such a tolerance.

200-Mil Magnetic Sound Track on 16-Mm Film "Perforated One Edge." After revision of the first draft, this

item was to be recirculated to the Subcommittee for letter ballot.

Stereophonic Sound Film, 35-Mm Composite Picture and Sound. Note was taken of the fact that this type of system is a reality today. It was urged that standardization procedures be initiated.

"EMBRYONIC NATURE" OF QUADRUPLE-TRACK PROPOSED STANDARD EMPHASIZED

It was decided to emphasize the "embryonic nature" of any initial draft of any proposed standard in this matter. The aim here was to prevent the idea from getting around that the mere act of *proposing* an American Standard carried with it any implication or indication of automatic approval on the part of the SMPTE. It was agreed to have a draft written on the matter of track placement for circulation to the entire Subcommittee.

MORE DEBATE ON THE AMPEX PROPOSAL

The existence of different viewpoints on the Ampex proposal for more high-frequency boost in recording was quickly revealed [just as similar differences were revealed during the discussion on reproducing equipment for quadruple-track stereophonic film systems. That discussion is reported elsewhere in this review.—*JP*]

Dr. Frayne showed a lantern slide of a proposed preamplifier reproduce characteristic for four-track stereophonic systems.

C. H. Wirth, of the Ampex Electric Corporation, presented a slide showing a reproducing characteristic which differed from the one shown by Dr. Frayne chiefly in the region above 3000 cps. Mr. Wirth argued, on behalf of Ampex, that a standard *recording* characteristic should also be developed. His argument was that the recording and reproducing characteristics are interdependent and that sound quality could be improved appreciably by additional high-frequency pre-emphasis.

Several people expressed disagreement with the Ampex position. Mr. Ryder thought the proposal had merit and should be given serious consideration. Dr. Frayne observed that the studios have been generally opposed to much high-frequency pre-emphasis.

W. F. Kelley, of the Motion Picture Research Council, agreed to draw up a proposal on reproduce characteristics for magnetic four-track stereophonic systems, taking into consideration any material Mr. Wirth might care to present along with any data which might be yielded by the studies now going on under the auspices of the Motion Picture Research Council. Mr. Kelley said he did not believe he could complete his assignment prior to January, 1954.

Basic Principles of Stereophonic Sound

An extended discussion of sterophonic principles was offered by William B. Snow.[9] He began by pointing out that stereophonic reproduction enhances both realism and listening pleasure; he cited an attempt at quantitative measurement: The observers listened alternately to single-channel and stereophonic reproduction. Low-pass filters had been inserted in the stereo system whereas the *single* channel was maintained flat to 15 kc. Half the observers preferred the stereophonic arrangement *even when the low-pass cutoff was reduced to about 5 kc.*

BASIC NOMENCLATURE AND DEFINITIONS

Mr. Snow indicated that differences in nomenclature had arisen. The words "binaural" and "stereophonic," for example, are used most frequently but not with uniform meanings. All this may have begun with Alexander Graham Bell who, in 1880, had referred to the "stereophonic phenomenon of binaural audition."

The speaker offered a few basic definitions. He attached the label "binaural" to a system employing a pair of microphones—preferably in an artificial head—a pair of independent amplifying channels, and a pair of independent, individual headphones for each observer. This, he said, duplicates normal listening.

He applied the term "stereophonic" to a system employing two or more microphones spaced in front of a pickup area with each individual microphone connected by a separate independent amplifying channel to its own loudspeaker. The speakers are spaced in front of the listening area. This, he declared, creates the illusion of sounds having direction and depth in the area between the loudspeakers.

A binaural transmission system, said Mr. Snow, actually *duplicates* in the listener's ears the sounds he would hear at the pickup point and gives full normal directional sense in all directions, *with the one drawback that the listener cannot turn the dummy head.*

A stereophonic system, on the other hand, produces an *abnormal* sound pattern at the listener's ears which his hearing sense interprets as indicating direction in the limited space between the loudspeakers.

"It has been aptly said that the binaural system transports the listener to the original scene, whereas the stereophonic system transports the *sound source* to the listener's room."

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[9] Consultant in acoustics, Santa Monica, California. Mr. Snow's paper, under the title "Basic Principles of Stereophonic Sound," and the extemporaneous discussion from the floor which followed it were published in full in *J. Soc. Motion Picture Television Engrs.*, **61**, 567-589 (November, 1953).

COMPARISON—MONAURAL, DIOTIC, BINAURAL, "MONOPHONIC," AND STEREOPHONIC SYSTEMS

In a table entitled "Electro-Acoustic Sound Reproducing Systems," Mr. Snow summarized the various systems:

Monaural. He equated this to listening with one ear plugged. One microphone, one channel, and one headphone are used. Directional effects are *not* duplicated in this system.

Diotic. The equivalent normal experience for this is "sound source in median plane only." A diotic system is characterized by one microphone, one channel, and *two* headphones. Each ear receives a single pulse. There is zero time difference and zero quality difference between the sounds received by the two ears. The result is only *partially* equivalent to the real thing, since directional effects of elevation are not duplicated, nor is the directional effect of room reverberation present. Qualitatively, said Mr. Snow, the diotic system is much superior to the monaural, where the listening is done with a single headphone applied to one ear.

Binaural. The equivalent normal experience is ordinary listening with the head *stationary.* A binaural channel is characterized by two microphones in an artificial head, each one feeding a separate channel which, in turn, feeds a separate headphone of a pair of headphones. Each ear receives a single pulse. The time difference between the two signals may vary from zero to 0.6 msec. The quality differences perceived by each ear are the *normal* quality differences perceived during actual listening without benefit of intervening electrical systems. The directional and quality effects of normal listening in the *pickup* room are duplicated throughout a 360-degree sphere. There are no *listening* room effects. The observer cannot turn to face the virtual source.

"Monophonic" Ordinary Loudspeaker. The effect here is that of sound coming through a hole in the wall. Such a system utilizes a single microphone, a single channel, and one loudspeaker. Each ear receives a single pulse. The time difference is zero. Both ears are used, and there are no quality differences so far as the two ears are concerned. This amounts to *binaural listening to a single fixed sound source position.* The effect, as perceived by the listener, is a composite of pickup and listening room acoustics. Such a system can represent one of widely spaced "effects" loudspeakers.

Stereophonic. Mr. Snow pointed out that there is *no* equivalent normal experience for this type of system. A stereophonic system may use two or more microphones, two or more channels, and two or more loudspeakers. Each ear receives two or more pulses, depending on the complexity of the system. Time differences may range from zero to more than 30 msec, and complex quality differences may be expected. In a stereophonic system, the psychological effect depends on "fusion of multiple pulses by the ears." As for the directional and quality effects of normal listening, these are *"simulated* for a *limited angular area* appearing as a part of [the] *listening room."* (Mr. Snow explained that 360-degree simulation would require a large number of channels.) The particular acoustical character of the sound, as perceived by the listener, is a composite of pickup room and listening room acoustics. As for reverberation, it has *partial* directivity in the *pickup* room and *full* directivity in the *listening* room. The "observer can turn to face [the] virtual source." Time differences from both source and observer positions play a part in creating the illusion.

Pseudo or Bridged Stereophonic. There is no equivalent normal experience for this type of system either. Such a system utilizes one microphone, two or more channels, and two or more loudspeakers. Each ear receives two or more pulses. Time differences may range from zero to more than 20 msec. There will be small quality differences. This type of system is characterized by a *single* original source. In many respects, the effects secured will be identical with those secured with *true* stereophonic systems. Any time differences perceived will be from the *observer* position only and, in the words of Mr. Snow, "detrimental." The signal-reverberation pattern will be identical for each loudspeaker. The quality of the sound emanating from each loudspeaker will be identical. Many different types of bridged combinations are possible.

HEARING CHARACTERISTICS AND THE DIRECTIONAL SENSE IN BINAURAL LISTENING

With respect to the properties of hearing which afford the directional sense in *binaural* listening, Mr. Snow offered the following data: For *pure* tones, angular localization is produced partially by *phase differences* at the ears, caused by the difference in distance from the source to the ears as the source angle changes. "The phase effect becomes ambiguous somewhat above 1000 cps, because at short wavelengths more than one angle results in the same phase difference. However, in the higher frequency region, intensity differences produced by the *diffraction* or *sound-shadow effects* of the head and external ears become great enough to give angular localization."

Mr. Snow reminded his audience that the great majority of sounds are *not* pure tones but *complex* tones. For the latter, the equivalent effects, he said, are *arrival time* and *quality difference.* "A complex wave pulse has an initial wavefront which arrives at the *near* ear a short time before it arrives at the *far* ear. It is this small time difference which is used by the hearing sense to determine small angular variations, particularly for sounds near the median plane

(straight ahead). It is characteristic to turn toward a source to locate it with maximum precision, and for impulsive sounds, such as speech or clicks, differences as small as 1 degree to 2 degrees can be perceived. These angles correspond to arrival-time differences of about 10 to 20 μsec, and the maximum possible difference, for a source in line with the two ears, is only about 700 μsec. The loudness differences at such small angles are negligible and it must be assumed that the arrival-time differences give the localization clues."

The arrival-time effect is aided by the quality differences at the ears caused by sound diffraction. "Quality difference is another way of saying that a change in waveshape is produced. The intensity differences due to diffraction are functions of frequency and cause a complex sound to have a different frequency-intensity composition, or quality, at each ear. It is undoubtedly this effect which removes ambiguities in direction which would result from arrival time [differences] alone, because the diffraction effects are so complicated that a given quality difference can correspond only to one direction. Quality differences also change most rapidly near the median direction; consequently, angular localization is much less precise at the side than in front or back.

"Changes in both arrival time and quality are relatively small," Mr. Snow continued, "as a source is elevated in front of an observer. Therefore the ability to distinguish angle in the vertical direction is relatively poor."

In binaural systems, perception of the sound source's position in space involves the determination of *distance* as well as *angle*. The ear has no mechanism corresponding to that of the eye for converging on the source and must depend on *less* definite clues. [Incidentally, the role of the convergence arrangements in human vision in distance determination has been disputed. Convergence plays an important part, according to some investigators, in gauging distance at very *close* distances—say, up to 3 or 4 feet—but is not significant when the distance is 200 or 500 feet; in measuring distances of *that* magnitude, say these investigators, human vision relies on cues *other* than the "muscular" or "kinesthetic" cues which are supposed to accompany convergence.—*JP*]

In the absence of reverberation, the only information given in a binaural system, said Mr. Snow, concerns intensity and quality. From past experience, the ear can estimate distance through its interpretation of the *absolute* loudness of the sound and through its judgment of any quality differences produced by atmospheric absorption. *These comparisons are made with a mental image of what the sound should be.* [Italics mine. Note that Mr. Snow here indicates the *experiential* nature of distance perception in binaural hearing. There can be no question that distance perception in *seeing* is also experiential to a considerable degree, as is the very process of seeing itself.—*JP*] If there is reverberation, the ear can judge approximate distance by the ratio of direct to reverberant sound. Since neither of these methods is precise, judgment of source distance is much less accurate than perception of source angle.

THE "INFINITE SCREEN" ANALOGY IN STEREOPHONIC REPRODUCTION

"It has become customary to describe stereophonic reproduction as follows," said Mr. Snow. "A screen consisting of an extremely large number of extremely small microphones is hung in front of the sound source. Each microphone is connected to a corresponding extremely small loudspeaker in a screen of loudspeakers hung before the audience." The sound projected at the audience is then expected to be a faithful copy of the *original* sound, and an observer is supposed to hear the reproduced sound in true auditory perspective.

It is customary to state, explained Mr. Snow, "that such an impractically large number of channels is not needed and that good auditory perspective can be achieved with only two or three channels."

The notion, then, is that the "myriad loudspeakers of the screen, acting as point sources of sound identical with the sounds heard by the microphones," will project a true copy of the original sound into the listening area. The observer will then employ ordinary *binaural* listening, and his ears will be stimulated by sounds identical with those he would have heard coming from the original sound source in the air without an intervening electromechanical system.

THREE-CHANNEL SYSTEMS *vs* THE "INFINITE SCREEN" ANALOGY

An arrangement using three channels "does indeed give auditory perspective," Mr. Snow apprises us, "but what has not been generally appreciated is that conditions are now so different from the impractical 'infinite screen' setup *that a different hearing mechanism is used by the brain.* [Italics mine. This point cannot be emphasized too strongly.—*JP*] Each individual loudspeaker sends a pulse to the observer. He therefore receives *three* faithful copies of the sound at *each* ear in rapid succession. The time differences between these pulses are too short to allow the ear to distinguish them as separate [pulses]; consequently, the hearing mechanism fuses them into an *illusion* of a single sound pulse coming from a virtual sound source located somewhere in the space between the outer loudspeakers. . . . This type of listening falls *outside* of *normal* experience," said Mr. Snow, "but fortunately the brain is able to form a single, *concise impression* from what might be expected to be a confusing set of signals sent to the ears. . . . The reverberation follows as a 'smear' of echoes of random di-

rectivity and does *not* create a virtual source illusion." [Italics mine.—*JP*]

Mr. Snow sums it up: "The problem, then, in stereophonic reproduction is to produce multiple sound images at the ears of the observer which will fuse in such a way as to give the desired *illusion* of sound origin."

SHIFT OF VIRTUAL SOURCE BY GAIN VARIATION

"With positions of source and observer fixed so that all other factors are constant, variation of the gain controls in the channels can shift the virtual source to any angular position in the reproducing area. This is true," Mr. Snow continued, "for any combination of source and observer positions. In practice, this is important because gain is easily controlled, to correct faults in pickup or to enhance angular movement. . . . As this is written many pictures are being made 'stereophonic' by the use of volume controls in bridged channels from sound tracks originally recorded for single-channel or 'monophonic' reproduction.

"The pseudo-stereophonic approach has its place, but it is not a satisfactory substitute for a real stereophonic pickup. It does not have the benefit," Mr. Snow asserted, "of the other aids to angular or depth perception described below; and, in particular, it can be used on only a single source at one time, so that an individual source and 'pan-pot' must be supplied for each sound."

QUALITY DIFFERENCES AND DIRECTIVITY

In a stereophonic system, if the microphones "have varying directivity with frequency, there are quality differences as well as intensity differences in the channels as the source moves. Angular localization is definitely affected by this. *It has been found that the higher frequencies, where the head has relatively high directivity, contribute most to stereophonic localization. Localization tends toward the loudspeaker giving greatest high-frequency output if the over-all loudness is the same.*" [Italics mine.—*JP*]

Quality differences will be interpreted in the stereophonic illusion as differences in direction, says Mr. Snow.

LOW FREQUENCIES AND LOCALIZATION

As for the very low frequencies, they "contribute essentially nothing to stereophonic localization. For example, poor localization results if 1000-cycle low-pass filters are inserted, and no difference in localization is produced by eliminating frequencies below 300 cycles. It has been found that much of the stereophonic effect is preserved if low frequencies are reproduced from only one low-frequency unit and side channels reproducing only frequencies above 300 cycles are employed." Mr. Snow emphasized the economic importance of this attribute of stereophonic systems—particularly *home* systems. He preferred to suspend judgment, however, on the above approach—so far as motion picture and auditorium reproduction with their added requirements of fidelity and flexibility are concerned—until a great deal more study of the matter is reported. He granted, however, that in the case of special effects loudspeakers, the low frequencies do not appear to be necessary *if the main object is to secure localization.*

ARRIVAL-TIME DIFFERENCES AND LOCALIZATION

Drawing on his own experience with stereophonic systems, Mr. Snow stated that the effect of differences in arrival time "is to make localization tend toward the loudspeaker from which the pulse arrives first." This effect, said Mr. Snow, is strong for small differences—say, up to 3 or 4 msec—but tends to become weaker for *greater* time differences. "The effect is relatively independent of where the differences are produced, whether on the pickup stage, in the listening room, or in the reproducing channels. Therefore, differences in one section add to those in another or can be made to compensate each other." These effects "can be largely compensated by intensity or quality differences inserted in the channels, for any one observing position."

DIRECT-TO-REVERBERANT SOUND RATIO

In a stereophonic system, the ratio of direct-to-reverberant sound is a factor that *may* contribute to angular localization. Experience has shown, however, said Mr. Snow, that it plays a very minor part in this.

DEPTH PERCEPTION IN STEREO

"Depth perception in stereophonic reproduction is controlled by essentially the same factors as in ordinary binaural listening . . . absolute intensity, quality, and ratio of direct-to-reverberant sound. As the sound intensity decreases, the impression is produced of the sound moving away. The same illusion accompanies a relative loss of high frequencies." The factor contributing most effectively to the feeling of depth, continued Mr. Snow, "is change in the ratio of direct-to-reverberant sound on the *pickup* stage. As the reverberant energy becomes more prominent, the source appears to recede on the *virtual* stage."

ALL OBSERVING POSITIONS NOT EQUALLY GOOD

Mr. Snow conceded that in stereophonic listening all observing positions are not equally good and that this is a "truly serious problem" in the theater. "Here the very factors which produce the stereophonic effect prove a disadvantage in some respects and measures must be taken to compensate them."

"HOLE-IN-THE-CENTER" EFFECT

In re the number of channels to be used. "Two channels give a large measure of the spacious effect desired for stereophonic reproduction and will give fairly accurate localization for a small stage. Such a system, on an ordinary-sized stage, will give quite different localization impressions to observers in different parts of the auditorium and is apt to suffer from the 'hole-in-the-center' effect where all sounds at center stage seem to recede toward the back. Nevertheless, for a use such as rendition of music in the home, where economy is required and accurate placement of sources is not of great importance, if the feeling of separation of sources is preserved, two-channel reproduction is of real importance."

TWO-CHANNEL STEREO SYSTEMS

To back up this idea, Mr. Snow cited the current use in many parts of the country of a broadcast station's FM transmitter for *one* channel and its AM transmitter for the *other* channel. Experience in his own home had convinced him, he said, that this type of transmission affords a great increase in enjoyment.

"Various methods for utilizing a single carrier for this type of broadcasting have been proposed, using upper and lower sidebands separately, simultaneous AM and FM modulation," and the modulating of one channel on a subcarrier which is then modulated with the *other* channel on a regular FM transmitter. "For such service, the idea of supplying only one low-frequency loudspeaker appears important." Mr. Snow asked us to recognize that "a poor cross-talk ratio between channels in such a stereophonic system is not serious, because the relative intensity levels in the two channels never become greatly different." Thus, systems whose individual channels are not quite suitable for high-quality, *single*-channel reproduction may be usable in stereophonic systems.

STAGES AND AUDITORIUMS

"Three channels appear to be a good economic choice for ordinary stages and auditoriums," said the speaker. ". . . For unusually wide stages additional channels have been found necessary. At present, it may be taken as a rule of thumb that additional channels should be considered when stage dimensions require channels spaced more than 25 feet on centers."

EFFECT OF PICTURE ON LOCALIZATION

"For sound-picture reproduction, the effect of the picture is great and the precision of localization required is smaller. If the sound tends to be in the region of the visible source, it will be localized there. Consequently, here it *is* possible to create the illusion of sound outside the farthest loudspeaker."

TIPS ON MICROPHONE PLACEMENT

Mr. Snow informed us that microphone placement can be used to advantage in creating the stereophonic illusion, which is "a compromise between favorable and unfavorable factors. . . ." He assured us that the "motion-picture industry is rapidly developing the art of microphone movement for stereophonic recording where action and movement of camera are all-important."

THE GEOMETRY OF PICKUP STAGES

To secure "the illusion of action on a rectangular stage requires a greater stage width at the rear line than at the front . . . and some compromise must be made; so the side microphones are usually placed somewhat inside the edges."

The matter of directional microphones was discussed by Mr. Snow: "Since to produce an angular illusion it is necessary to generate intensity differences in the channels, a study of the geometry will show that greater movement is required at the rear of the pickup stage than at the front to produce a given angular impression. If the microphones are directive, greater intensity changes will occur as a source moves across the stage from the lobe of one microphone into that of another and the rear line will be shortened. At the front line the directivity effect may be so great that the sound appears to recede between microphones. Experiment has shown that with moderate directivity, and by toeing in the lobes of the side microphones somewhat, an advantageous compromise between these two effects can be made and better over-all coverage of a rectangular stage obtained."

Mr. Snow contrasted the problems of multiple-microphone pickup in single-channel and stereo systems: "In monophonic systems multiple-microphone pickup often leads to poor fidelity because of cancellation between the signals from the microphones in specific frequency regions. In stereophonic systems this effect is ameliorated because sound is fused from several sources."

AMPLIFIERS FOR STEREOPHONIC SYSTEMS

"Amplifiers used in stereophonic systems do not differ from those of monophonic systems except in number," said Mr. Snow. "The characteristics of the amplifiers in the various channels should be similar and the gain should be stable so that no undesired level differences will occur. It is usually found desirable to have a ganged volume control, which will adjust the over-all level, and an individual control in each channel for balance or intentional unbalance settings. Similar provisions for quality-changing networks are desirable."

NOISE, DISTORTION, AND FLUTTER TOLERANCE IN STEREO SYSTEMS

"The consensus of reported opinion in the literature is

that stereophonic reproduction reduces the objectionableness of distortion and noise," declared Mr. Snow. ". . . no test data are available to show whether the distortions become less detectable by the observer, or whether he is willing to overlook more distortion because of the increased pleasure of listening provided by stereophonic sound. Doubtless both reasons are true in part . . .

"In monophonic reproduction any noise (distortion products are equivalent to noise) competes directly with the signal for attention whereas in stereophonic reproduction the directional illusion separates noises and program in space and allows the observer to concentrate more on desired sounds. Moir and Leslie report a 12-db improvement in signal-to-noise ratio 'due to the ears' steerable directivity pattern.' "

Flutter, too, Mr. Snow felt, seems to be not as noticeable in stereophonic reproduction.

FREQUENCY-RESPONSE MATCHING IN STEREO CHANNELS

"For ideal results," Mr. Snow suggested, "the quality of the various channels should be identical." Differences in quality will cause the virtual source to be localized subjectively at a point different from the *desired* point. "On the other hand, a stereophonic effect will be preserved even with fairly large differences in quality. Consequently, in practical operation, the attention now given to maintenance of uniform frequency response in high-fidelity monophonic systems will be adequate for the channels of stereophonic recording systems."

LEVEL MATCHING IN THE CHANNELS

"The level differences between channels should be kept small," Mr. Snow advised, "but the requirement does not seem inordinately difficult." For a 2-db unbalance between the channels of a two-channel system—"the most critical case"—the virtual source would be shifted about 4 feet across a 45-foot stage.

RE-RECORDING PROBLEMS IN STEREO

In preparing a conventional film recording for release, a very important function is the dubbing in of sound effects and music, or re-recording *with altered quality or balance.* "In stereophonic recording, there is the added requirement of proper position of the sound," said Mr. Snow. "When a single source must be given position, use is made of bridged system and 'pan-pot.' This is an arrangement of attenuators on a common control which will feed to each channel an intensity simulating the intensity it would have received if the original recording had been made with multiple microphones . . . the operator must adjust his settings to the desired effect."

MEDIA FOR STEREO SOUND

"The adaptability of tape- and film-recording methods to stereophonic sound is readily apparent," Mr. Snow pointed out, "and these strip media are relatively unlimited as to number of channels. For two-channel recording disk methods are also practical. Two systems have been demonstrated. In one, two grooves are used in parallel, one starting near the outer edge and one near the middle of the recording area. Two reproducers are used. In the other, a single groove is used, with one channel recorded as a vertical and the other as a simultaneous lateral track. While the interaction or crosstalk between channels is relatively high, experiment has shown that a sufficient ratio for stereophonic work can be obtained."

Discussion—Stereophonic Principles

"REAL" STEREO *vs* "PSEUDO" STEREO

Dr. Frayne asked if it were possible to duplicate the "real stereophonic effect by using the artificial method of taking a monaural track and making it . . . stereophonic by manipulation of gain and equalization."

Mr. Snow didn't think so, because "by manipulation of the channels you do not duplicate all the effects which you can get on a real stage." As a speaker walks across a stage during a *true* stereophonic presentation, Mr. Snow indicated, the actual effect of the intensity increase is secured and the arrival-time effect results automatically, with sound from the nearest channel arriving earliest. (Microphone directivity, said Mr. Snow, can be used to enhance both of these effects, if applied with care.) It would be very difficult, he added, for any single individual to duplicate the intensity-increase or the arrival-time effects merely by twisting knobs. Anything accomplished by artificial manipulation could be achieved for only *one* source at a time, he thought, whereas an *actual* pickup with a *true* stereophonic system would automatically handle all the factors involved for any number of sources simultaneously.

"My own feeling is that it is very unlikely that the completely artificial manipulation of channels will give you a real duplication of multiple-channel pickup at the original scene."

Mr. Snow felt that the pan-pot method of producing simulated stereophonic sound would help in many situations but should be eliminated as soon as possible. It should be used only as a "last resort . . ." he said. "It won't sound as good as the real pickup or the original."

HOW MANY CHANNELS FOR GOOD STEREO EFFECT?

The number of channels that should be used, Mr. Snow commented, depended on the width of the stage, the width

of the scene to be covered, and "perhaps, as a rule of thumb, you might say that a channel should not cover more than a width of 20 or 25 feet." The fundamental principles involved in stereophony would not change with the number of channels, he thought.

Dr. Frayne inquired whether it was possible to cover a 65-foot screen with three speakers.

Mr. Snow appeared skeptical. With a picture on the screen, he indicated, it is not necessary to have the same order of sound localization "as when you're only trying to reproduce an orchestra with nothing to look at, as I have usually done in my work. The picture certainly can complement the 'monophonic' sound to some extent, as we're all well aware, since we've been getting along with one channel on *any* width screen up to now."

A more realistic presentation would result, he felt, if *more* than three channels were used, but he conceded that it was a matter of economics.

CAN LOCALIZATION BE "PULLED" PAST THE "OUTSIDE" LOUDSPEAKER?

Edward S. Seeley, of the Altec Service Corp., New York, asked if it were possible to re-create a location outside or beyond the outermost speaker in a three-channel system.

Mr. Snow replied that there didn't seem to be anything of a purely physical or physiological nature that would effectively "pull" the sound past the outside loudspeaker *if the spectator were to keep his eyes closed.*

On the other hand, if a particular sound source in the original scene were spatially beyond the outermost speaker of the reproducing system, it would not be very difficult for the spectator in the theater to *imagine* that the particular reproduced sound to which he was listening was, in effect, originating somewhat *beyond* its actual *physical* point of origin in the reproducing system. Watching the screen would help.

Mr. Walter Brecher of Leo Brecher Theatres raised the question of whether stereophonic systems would be effective in many of the neighborhood theaters, whose total width is no more than 30 or 40 feet: ". . . in view of the acknowledgment that the visual 'pull' *does* affect the illusion of location of sound source, does stereophonic sound offer any substantial benefit for a theater of the dimensions that I have described?" he asked.

Mr. Snow answered that a stereophonic system would "improve the reproduction in a living room where the loudspeakers are 5 feet apart or 12 feet apart . . ."

"PANNING" SOUND BY PHASE DISPLACEMENT

Referring to the "panning" of sound, Mr. Ryder reported that by using phase displacement rather than volume manipulation, "we can more definitely control the placement of sound than by the volume difference between loudspeakers. We also find that equalization, as mentioned by the speaker [Mr. Snow], is a very strong control."

Physical displacement amounting to as many as four, and even seven, sprocket holes had been used at Paramount to control the listener's subjective impression of sound source position. [A physical shift of four sprocket holes in sound-track editing in 35 mm is equivalent to a displacement in time of 1/24 of a second; eight sprocket holes is equivalent to 1/12 of a second.—*JP*]

When the phase shift method is used, said Mr. Ryder, the specific volume levels at which each one of the three speakers plays back has little effect on the listener's personal illusion as to where the sound source, as re-created in the theater, actually is.

By means of the phase displacement technique, claimed Mr. Ryder, ". . . we can gain a proper directivity much farther to the side of the theater and farther down toward a side loudspeaker than we have ever been able to obtain either by volume control or by classical stereophonic sound." Mr. Ryder pointed out that his remarks applied equally to dialogue, music, and sound effects.

In the picture *Shane,* he said, there are sequences in which the violin section of the orchestra comes out of the *left*-hand loudspeaker, the bass comes out of the *right*-hand speaker, and the dialogue issues from the speaker at the center of the screen. Meanwhile, calls are heard from the *left* side of the screen, and sound effects appear to move back and forth.

"We find no trouble," said Mr. Ryder, "in gaining proper placement of sound effects, and we find no confusion when these sounds are ultimately reproduced in the theater." He recommended that those who had not experimented with phase shifting do so. He offered the opinion that "there is a great deal still to be learned in regard to the effective handling of sound when reproduced from three or more loudspeaker systems." There are many ways of conveying a given effect to the audience, Mr. Ryder emphasized. The real question is "which way is the simplest, least costly, and least subject to error and disturbing effects."

TIMING *vs* INTENSITY CHANGES IN SHIFTING VIRTUAL SOUND SOURCE

Col. Richard H. Ranger, of Rangertone, Inc., Newark, New Jersey, backed up Mr. Ryder's statement to the effect that timing has a pronounced effect on directivity. Col. Ranger credited Dr. Haas of Göttingen for elucidating the matter.

The Colonel agreed that the illusion of a sound source moving across a stage could be achieved solely by timing, but the apparent source could also be moved, he pointed out, by *intensity* manipulation. The two effects could be

used to compensate and to complement each other, said Col. Ranger. "In other words, you can move the timing so as to make the apparent location move to the left, we'll say, and you can increase the intensity to hold it where it was," he added. ". . . you soon find . . . that the timing completely outweighs the intensity, so that actually the timing becomes in many ways the controlling factor."

Col. Ranger cautioned that it is possible to "overdo the timing business" and indicated that he did not consider timing to be the *only* essential factor. The best approach, in his opinion, was judicious use of *both* timing and intensity control.

Mr. Ryder agreed that it is possible to control the illusion of source placement by means of intensity changes. Very smooth control could be achieved, he maintained, by manipulating timing, equalization, and volume. He cited the picture *Shane* "which is largely handled by timing and not by volume." Mr. Ryder further expressed the view that in motion-picture editing, where changes in sound placement are often necessary when cuts are made [apparently, Mr. Ryder also meant "cuts" *from one angle or point of view to another*, as the jargon of film production goes.—*JP*] "I personally favor a minimum of movement of dialogue and a maximum use of stereophonic [sound] for punctuation in story-telling, for effects, and music."

PERCEPTION OF FLUTTER

Col. Ranger emphasized that the subjective perception of flutter and other factors affecting quality depended largely on *which* sound reaches the listener first. "You can have considerable flutter, if you please, in the sound that comes later, and it will not affect the apparent quality at all."

TWO-CHANNEL STEREOPHONIC SYSTEMS

At one juncture Mr. Snow indicated that it would be difficult to create any kind of a proper illusion in the theater if only *two* channels were used, as had been urged by some. The use of only two channels in a stereophonic system would make the pickup problem more difficult, he said, "particularly when so much of the sound should come from the center of the stage for close-ups."

[It should be noted that in the foregoing comment Mr. Snow was not talking about a *binaural* system but a *stereophonic* system. Unfortunately, there is a tendency among many people to label *any* system having two channels "binaural" and all systems having three or more channels "stereophonic." Harking back to Mr. Snow's definitions (given earlier in this review), we find the chief criterion of an *electromechanical binaural* system to be that the sound output of one channel is fed to one ear and the sound output of the *second* channel to the other ear. The identity of each channel, from microphone to individual ear, is preserved. In the present state of the art, this seems to preclude anything but earphones as the ultimate transducers because in no other practical manner does it seem possible to preserve the separateness of the two channels. The stereophonic system, on the other hand, is something entirely different. In its idealized form, as Mr. Snow neatly delineates it, a stereophonic system consists of an infinite number of microphones, each feeding its own channel which, in turn, feeds its own loudspeaker. The seven-channel system of Cinerama and the three-channel system of CinemaScope are each economic and practical versions—*compromises*, to be sure—of the "infinite screen" idea. A *two*-channel system in which each channel feeds a separate loudspeaker is a *further* compromise version of the "infinite screen" idea. Pursuing the logic of Mr. Snow's definitions, the particular attribute of the latter system which makes it *stereophonic* (and *not* binaural) is the fact that *each* pulse emanating from *each* loudspeaker will be received by *each* ear of our two-eared human listener. There may (and probably *will* be) arrival-time differences, intensity differences, diffraction-effect differences, quality differences and the like, in the manner in which any particular pulse emanating from one loudspeaker of the pair is perceived by the two individual ears of the listener's pair of ears.—*JP*].

Conversion of Theater Projectors into Magnetic Record-Playback Machines for "Lip-Sync" Work

George Lewin, Chief of the Sound Branch at the Signal Corps Pictorial Center, Astoria, L. I., told the SMPTE Convention how a pair of standard 35-mm, theater-type, arc-lamp projectors were converted into magnetic recording and playback machines for use in "lip-synchronization" work. Much work of this kind is done at the Signal Corps when foreign-language dialogue is added to films made originally with English-speaking sound tracks.

Mr. Lewin's team on this project included James J. Kennedy, Jr., W. Norman Kessel, Stephen Szeglin, and Rudolph Peters. Beginning with a conventional composite print (picture and photographic track) to which a magnetic stripe had been added, and which had then been broken down into short loops, they evolved a method which completely eliminates all use of photographic sound-track raw stock (as well as processing) up until the moment when the final release-print track negative is to be recorded. If a particular "take" is no good, any number of additional "takes" can be recorded on the same magnetic stripe, until a good one is obtained, without the waste of any film. This saves not only raw stock but editing time as well. In addition,

the system provides the director with an instantaneous check of synchronization (as well as dramatic quality) before the cast is dismissed.

Because each projector [whose only function in conventional "lip-sync" procedures is to throw a picture on the screen and provide the director and the actors with a cue track—*JP*] becomes a record-playback machine as well, the regular complement of photographic and magnetic recorders of the Signal Corps Pictorial Center is freed for other work.

MAGNETIC STRIPE HALF COVERS PHOTOGRAPHIC TRACK

The new system utilizes a magnetic stripe 110 mils wide. This width was selected as being probably the minimum width for a satisfactory signal-to-noise ratio, said Mr. Lewin. The stripe is positioned in such a way that one of its borders coincides with the center line of the composite print's photographic sound track. The other border of the stripe encroaches slightly on the composite print's picture area. The uncoated half of the original photographic track [presumably an English-speaking track—*JP*] remains available for cueing purposes.

RCA HEAD "MARRIED" TO WESTREX OSCILLATOR AND AMPLIFIERS

An RCA magnetic head is used on each projector in this initial installation. The availability of RCA mounting kits for magnetic reproduce heads helped out considerably, as did the fact that the heads could be used for recording as well as for reproduction.

The erase head used on each projector is of Westrex make. Serving both projectors are a single Westrex bias oscillator, a single Westrex record amplifier, and a single Westrex playback amplifier.

An ingenious approach was used to minimize splice noise. [Because the film loops used in conventional "lip-synchronization" procedures are generally made up of a section of composite print—containing the usual picture and photographic sound—plus a section of leader, each film loop contains at least two splices. The latter can give rise to considerably greater disturbances as they pass the sound-scanning point than, say, conventional splices in quarter-inch tape.—*JP*]

In "lip-synchronizing" work the sound must frequently begin the instant the first frame of picture of the particular loop flashes on the screen of the "dubbing" stage. Because of the customary forward physical displacement of the sound track with respect to the picture, this means that the magnetic recording laid down on the loop must often start on the *leader* and continue *across the splice* which joins the leader to the composite-print section of the loop.

"Fairly good results were obtained," said Mr. Lewin, "using the electrical butt-weld type of splice, but there was still room for improvement." The idea of using diagonal splices was considered but discarded: First, no satisfactory diagonal butt-weld splicer was immediately available. Second, it was felt that diagonal splices might make it more difficult for the film editors to do an accurate job of assembly. [Film editors who "cut sound" in 35-mm practice customarily "cut to the sprocket hole." Since there are four sprocket holes on either side of a frame, any error causing a longitudinal shift of the track by a single sprocket hole is equivalent to a time displacement of 1/96 of a second. Any sprocket-hole errors which occur during track editing or assembly tend to be cumulative, and unless care is exercised, subsequent scenes may be knocked out of "sync." Because diagonal splices in sound tracks can make life more complicated for an editor "cutting to the sprocket hole" and thereby slow up production, Mr. Lewin and his team were desirous of avoiding diagonal splices.—*JP*]

DIAGONAL HEAD MOUNTING CUTS SPLICE NOISE

It was decided instead to rotate the magnetic head itself and fix it at an angle of 60 degrees with respect to the *conventional* head position. This, said Mr. Lewin, has the same effect as does a diagonal splice in reducing splice noise as film goes over the head. The drawback, of course, is that diagonal mounting of the head puts the modulation on a "bias," making it impossible to play tracks which have been recorded on the Pictorial Center's converted projectors on any of the usual magnetic film reproducers. This proved to be of no great consequence, because when the completed loops are reassembled into a continuous roll, they are re-recorded from the projector to a conventional magnetic track for use in the final "dubbing" to the photographic release negative. Besides, the moment a particular "take" has been approved by the director, the biased track is immediately transferred to standard magnetic track for protection.

Thus, the 60-degree orientation of the record-reproduce head permits the use of the ordinary straight-across, electrical butt-weld type of splice. It also permits use of the full 200-mil gap width of the head. Thus, although the magnetic stripe is only 110 mils wide, the head *effectively* scans a diagonal as wide as the gap, namely, 200 mils.

The general output level, with 60-degree placement, is at least 3 db higher, by actual measurement, said Mr. Lewin, than would be secured were the head positioned in the customary manner and thus made to scan a stripe effectively only 110 mils wide. On the other side of the ledger, the angular orientation results in a 6-db loss at 8000 cps compared with the ordinary gap loss which accompanies conventional, straight-across mounting. Equalization, we are told, has provided a fairly easy solution without "appre-

ciable penalty in noise level." Removal of the 180-ohm input termination normally used in the Westrex playback amplifier "automatically provided most of the high-frequency boost required. . . ."

Returning to advantages: The 60-degree position makes it unnecessary to scan the extreme edges of the 110-mil stripe. These edges, said Mr. Lewin, are not always strictly uniform, and considerable extraneous noise may be generated if they are scanned. If a head mounted straight across were cut down to miss the edges of the magnetic stripe, we are informed, there would probably be a reduction in output.

STRUCTURAL MODIFICATIONS

As might be expected, diagonal positioning introduced a number of mechanical problems. The head mount had to be modified so that the plane of the gap would always be held parallel to the plane of the oxide-coated film. Otherwise, said Mr. Lewin, head contact might change as a result of azimuth adjustments.

His team discovered, too, that the end of the head had a tendency to dig into the film and chip off tiny bits of emulsion; these would become encrusted on the head and build up in height until contact was lost. "This was solved by lapping away some of the iron on each side of the gap so that very little metal other than the gap itself contacted the film. The leading edge of the gap was also rounded off so that it would not dig into the emulsion. These modifications," said Mr. Lewin, "did not appear to alter the magnetic characteristics of the head."

To improve head-to-stripe contact, a spring-loaded roller was added to the film transport system in order to put a slight tension in the film. "This unfortunately increases the flutter slightly," reported Mr. Lewin, "but not enough to be objectionable for voice recording."

Hum pickup originating in the dc supply of the projectors' arc lamps was licked by moving the rectifiers outside the projection booth.

Because the ultimate magnetic sound-track roll is generally assembled from individual striped loops which have been recorded not on *one* projector but on *both* projectors, it is necessary for the pickup heads on the two machines to match each other very closely in azimuth and level. The matter is complicated somewhat by the fact that, in the initial installation, both projectors are served by the same amplifier and by the same bias oscillator. Rather than go into the extra circuitry and switching arrangements needed to provide automatic resetting of bias current, level and equalization as first one and then the other machine is cut in, the problem was avoided altogether by careful selection and adjustment of the heads so that the two projectors have been matched with ± 2 db as to both level and response.

OPERATING ROUTINE

The system is designed for continuous operation with no loss of stage time during the transfer of "O.K." magnetic takes to photographic sound-track raw stock or to standard magnetic track.

If the magnetic take made on Projector A, for example, is good from the standpoint of "lip sync" and general histrionics, the director calls, "Print!" This is the projectionist's cue to set Loop No. 2, which has already been threaded up on Projector B, in motion. Out on the sound stage rehearsals immediately begin on Loop No. 2 with the latter's photographic track (half covered over by the magnetic stripe) used for cueing purposes by the actors and/or the director, as required.

In the interim, while Loop No. 2 is being rehearsed, the projectionist keeps Loop No. 1 running on the first machine —Projector A; the arc lamp of this machine, however, has been turned off. The mixer then proceeds to transfer the magnetic recording which has just been laid down on Loop No. 1 to standard magnetic track for protection, or to photographic sound-track raw stock, if conventional editing techniques are to be used. The mixer has full control over this transfer operation. This applies even though a full-blown rehearsal is simultaneously taking place on the sound stage, with Loop No. 2's picture being projected on the screen and its own photographic track playing back through the stage loudspeaker or into the director's earphones—as the needs of the moment dictate. The fact that the mixer is engaged in a magnetic-to-photographic transfer operation at the moment does not—from a system standpoint—interfere with the rehearsal of Loop No. 2 in any way.

When the transfer of Loop No. 1's magnetic recording has been completed, the projectionist stops Projector A, unthreads Loop No. 1, and threads up Loop No. 3 on this same machine.

The mixer now turns his attention to Loop No. 2, which, by this time, is probably ready for a "take." And so on, *ad infinitum*, with no stage time lost for transfers.

Note: The reader is referred to the June, 1954, issue of the *Journal of the Society of Motion Picture and Television Engineers* for a considerably more extended treatment of the foregoing, plus photographs and diagrams. Other magnetic-recording techniques in regular use at the Signal Corps Pictorial Center are described in *J. Soc. Motion Picture Television Engrs.*, **56**, 653-671 (June, 1951). Data on splice-noise problems and "blooping" are given in *J. Soc. Motion Picture Television Engrs.*, **48**, 343-347 (1947).

Journal Authors

MORRIS L. GRODER, a graduate of Capital Radio Engineering Institute, Residence School, did post-graduate work in management engineering at George Washington University. From 1939 to 1942, Mr. Groder was employed as an engineer by the Home Recording Company, New York, where his duties included work on the design and development of sound recorders and recording blanks. From 1943 to 1945 he was an inspector of naval materiel. In 1947 Mr. Groder took the position of radio engineer at Columbia University, where he worked from the basic designs and verbal information furnished him by the University physicists to complete the design, construct, and supervise preliminary testing on their equipment. Mr. Groder went to Georgetown University in 1949 as a sound engineer, working on audio-visual equipment. From 1951 to the present, he has been with the U. S. Navy as an electronic engineer.

Mr. Groder, the author of several scientific articles, is a Senior Member of the IRE and a member of the AES, the Society of American Military Engineers, the Institute of Aeronautical Sciences, and the Institute of Navigation.

ALFRED JORYSZ

ALFRED JORYSZ was born in Vienna, Austria, in 1913. He attended the Vienna Institute of Technology and received the degree of M.S. in applied physics and radio engineering in 1937. In 1938 he was employed by the Presto Recording Corporation as a test and development engineer in the audio amplifier and disk-recording field. From 1941 to 1945, Mr. Jorysz was a project engineer on several U. S. Navy war contracts involving development work on sonar systems, sonar test equipment, special recording devices, and aerial navigation trainers. Since 1945, he has been the engineer in charge of the electronics laboratory of the Presto Recording Corporation, supervising the design and development of all types of instantaneous recording systems. Mr. Jorysz is a member of the IRE.

Fabian Bachrach

MARTIN V. KIEBERT, JR.

MARTIN V. KIEBERT, JR., attended the University of Idaho from 1928 to 1931 and Reed College during 1933 and 1934. He did graduate work at Bowdoin College in electromagnetic wave theory, transients, and electronics from 1942 to 1943, and in 1943 he took the Navy Radar Course at the Massachusetts Institute of Technology.

Mr. Kiebert has had over 23 years in the communications and electronic industry covering research, development, design, and administration. He was chief engineer of radio station KIRO, Seattle, Washington, and consulting radio engineer for nineteen Northwest radio stations. From there he went to the Federal Communications Commission in Washington, D.C., as an associate radio engineer in charge of all engineering for television, facsimile, high-frequency, and international broadcasting stations. He spent five and one-half years with the U. S. Navy, during which time he spent two years as senior instructor, N.T.S. (Radar), at Bowdoin College and three and one-half years with the Bureau of Aeronautics. With the Bureau he was in charge of FM-CW radar development and, later, technical direction and coordination of all missile control, guidance and stabilization programs. He also served one year as head of the Guided Missile Branch, Electronics Division.

Since his naval service, Mr. Kiebert has been associated with Sherman Fairchild and Associates, Raymond Rosen Engineering Production, Bendix Aviation Research Laboratory, Detroit, and Bendix Aviation, Teterboro, New Jersey.

A licensed commercial pilot, CAA, and professional engineer, Mr. Kiebert is also a senior member of the IRE, and a member of the SMPTE, AIEE, Institute of the Aeronautical Sciences, Franklin Institute, American Ordnance Association, and American Rocket Society.

WALTER O. STANTON was born in Canton, Ohio, in 1914. He studied electrical engineering at Wayne University, Detroit, Michigan. During the late 1930's he was employed as a development engineer by the Electronic Control Corporation. From 1940 to 1943, he was vice-president and chief field engineer for the Detroit Universal Duplicator Company, where he developed and patented an electronic servo system which enabled any standard machine tool to automatically produce complex contoured parts. From 1943 until 1948, Mr. Stanton was associated with the Control Instrument Company, a Burroughs Division, as assistant to the vice-president in charge of engineering, and as a liaison engineer to military customers. He went with Pickering and Company, Inc., in 1948, and has served as chairman and president since 1950.

In addition to patents granted, Mr. Stanton has been responsible for component and systems developments in the fields of industrial control, fire control and audio. A member of the AES, Mr. Stanton was elected a governor in 1953.